MAR 2

# *The Journal of*
# THE ROYAL AERONAUTICAL SOCIETY

CONTENTS FEBRUARY 1949

*THE CHARTER OF INCORPORATION*

*FRENCH TURBO-PROPELLER AND TURBO-REACTION ENGINES*
P. DESTIVAL

*DEVELOPMENT OF THE ARMSTRONG-SIDDELEY MAMBA ENGINE*
W. H. LINDSEY, M.A., A.F.R.AE.S.

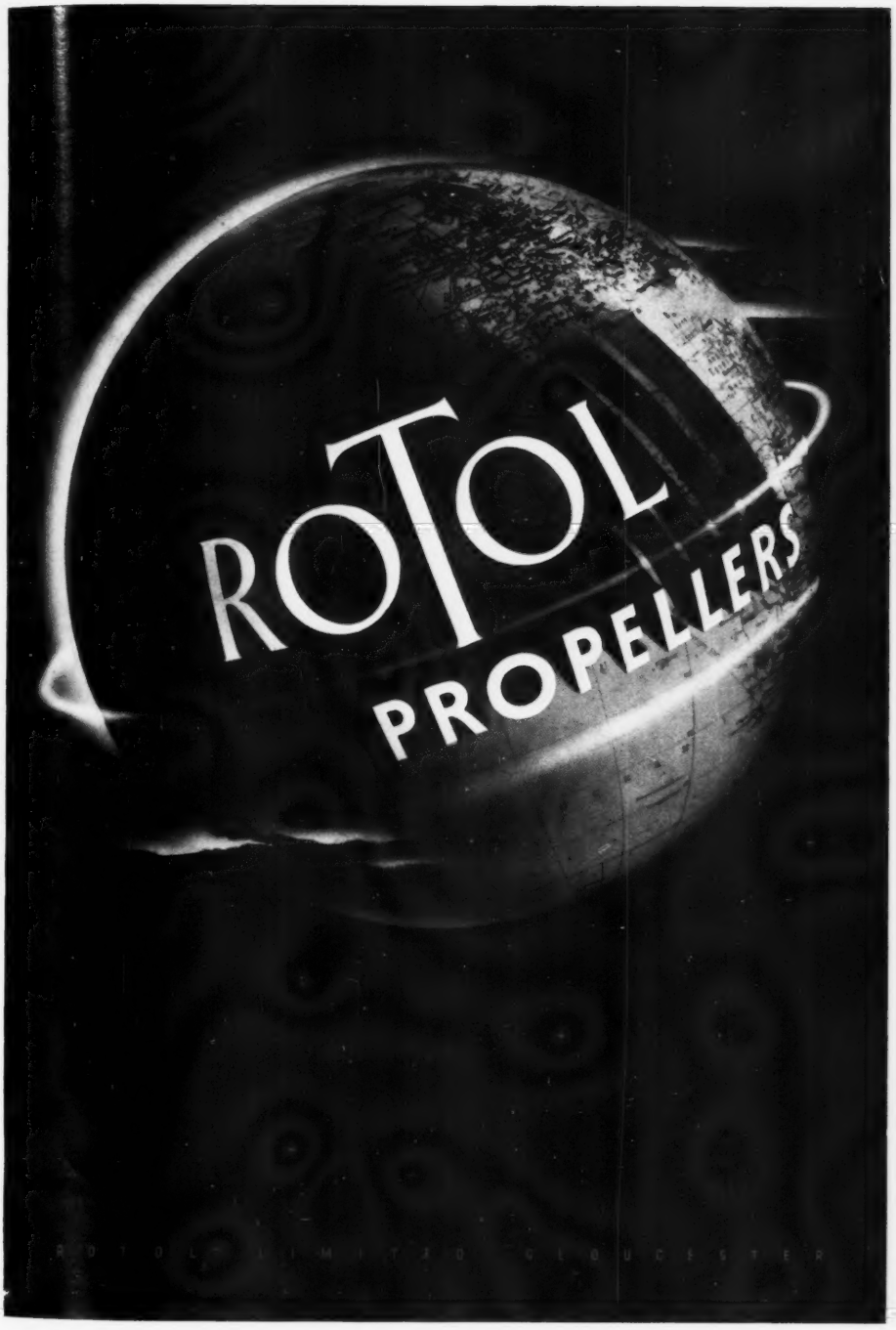
*ESTIMATION OF CRUISING AIR SPEEDS FOR ECONOMIC ANALYSIS*
ALAN H. STRATFORD, B.SC., A.F.R.AE.S.

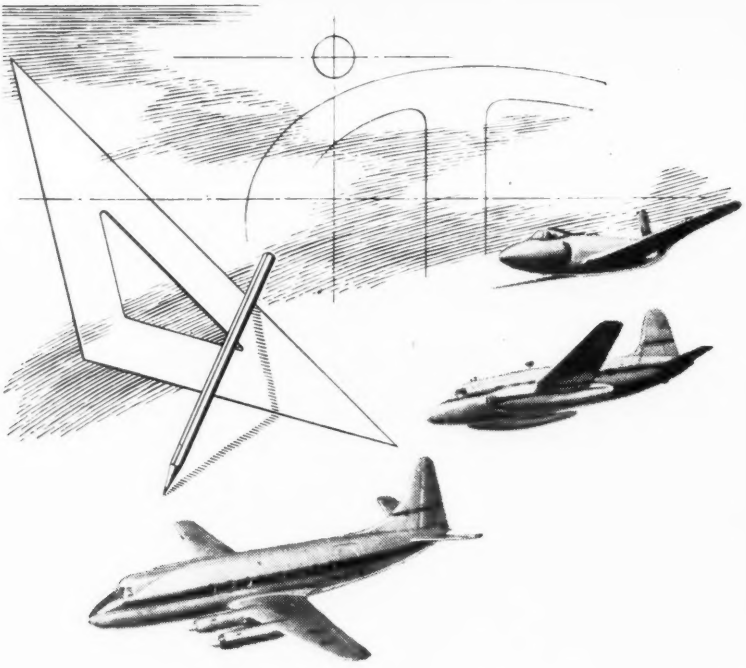
*AN AIRLINE'S ENGINEERING SERVICE EXPERIENCE AND ITS USE IN THE DESIGN OF AIRCRAFT*
H. S. CRABTREE, A.F.R.AE.S.

*REVIEWS*

*CORRESPONDENCE*

D. NAPIER & SON LIMITED · LONDON W.3


ROTOL
PROPELLERS



# JET HISTORY IN THE MAKING

Continual research and development have placed Vickers-Armstrongs ahead in the design and manufacture of jet aircraft. Of the three aircraft shown here, the Viscount is the first four-engined propeller-turbine airliner in the world; the Nene Viking is the first pure jet airliner, and the Attacker, which has achieved fame as the World's most manœuvrable high-speed fighter is now in production for the Royal Navy. This leadership is held today by the same organisation whose foresight and enterprise produced the sea-plane that won the Schneider Trophy outright for Britain, delivered Spitfires and Wellingtons ready for combat in 1939, and developed the first British post-war Civil airliner.

Vickers-Armstrongs Limited

AIRCRAFT SECTION · VICKERS HOUSE · BROADWAY · LONDON · SW1

A.T.48

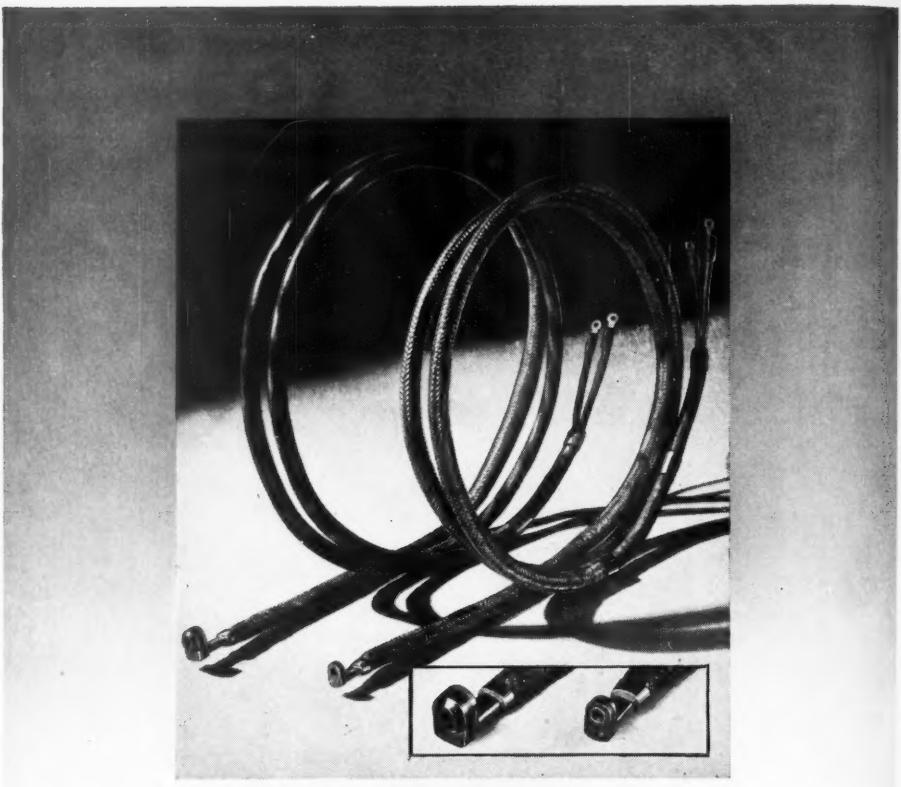
# The right approach . . .

*One Shilling weekly* — *Annual rate £3. 1s. post free*

## TEMPLE PRESS LIMITED

BOWLING GREEN LANE, LONDON, E.C.1. TERMINUS 3636

*Associated Aeronautical Publication:* "'THE AEROPLANE' DIRECTORY" *incorporating* WHO'S WHO IN BRITISH AVIATION



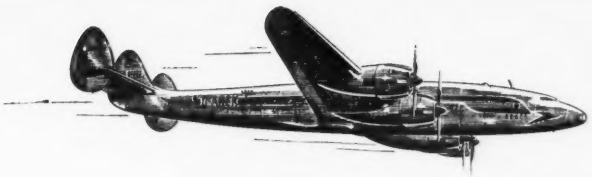
# WESTON *Thermocouple Assemblies*

A full range of Thermocouple Assemblies is available for use in conjunction with Weston Temperature Indicators. Copper and constantan are the standard materials employed, constantan being specially selected for the constancy of its thermo-electric characteristics against copper, and each thermocouple has the same E.M.F. temperature curve. Copper constantan compensating leads, of the duplex type are also supplied for connecting the thermocouple to the indicator. All thermocouples and leads comply with Air Ministry specifications and are interchangeable, being adjusted to a definite resistance. Illustrated are Types 11A and 14A Thermocouple Assemblies, designed for bolting to the cylinder head. Gasket type thermocouples for connecting under the sparking plug are also available.

**SANGAMO WESTON LIMITED**

GREAT CAMBRIDGE ROAD, ENFIELD, MIDDLESEX

**Telephone: Enfield 3434 & 1242**



# "I'm a pioneer in modern dress!"

These days, some people don't think that tradition counts for much. But I know better. Pioneering my own business twenty years ago taught me that tradition is a priceless ingredient that you have to earn. It's not something you can buy on the open market. The way I look at it, every tradition has a pioneer for a father and its mother is experience.

Take the example of B.O.A.C. . . . Its more than 72,000 miles of world-wide air routes to five continents and forty-two countries didn't just happen. There was always a first time for every route. Because B.O.A.C. has the imagination and the determination to be and stay a leader, it always looks and plans ahead.

That's why it's not surprising that B.O.A.C. pioneered the air route between Britain and Australia over ten years ago. Or that it was the first and for two years the only airline to fly the present North Atlantic route as a two-way, year-around service. Nor is it surprising that B.O.A.C.'s 30-year-old tradition of Speedbird service and experience is reflected by all its personnel.

Yes, I say — *never* underestimate the importance of tradition!

GREAT BRITAIN . USA . CANADA . MIDDLE EAST
WEST AFRICA . EAST AFRICA . SOUTH AFRICA
PAKISTAN . INDIA . CEYLON . AUSTRALIA
NEW ZEALAND . FAR EAST . JAPAN

**B.O.A.C. TAKES GOOD CARE OF YOU**

**FLY BY B·O·A·C**

BRITISH OVERSEAS AIRWAYS CORPORATION IN ASSOCIATION WITH Q.E.A., S.A.A., & T.E.A.L.

*The Handley Page* **HERMES IV**

*is equipped with* **DUNLOP**

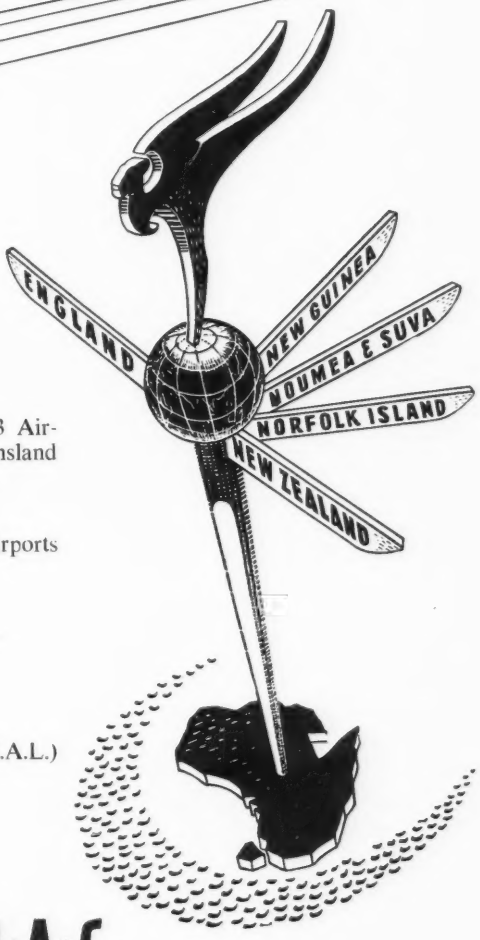
**WHEELS · TYRES · BRAKES AND**

**FLEXIBLE HOSE ASSEMBLIES**

DUNLOP RUBBER COMPANY LTD. (AVIATION DIVISION) COVENTRY

# WHERE QANTAS FLIES

*Australia's International Airline provides complete modern facilities for Air Travel, Air Mail and Air Cargo.*




● SYDNEY—LONDON
via Singapore, India, Egypt . . . 'Kangaroo' Service by Constellation.

● SYDNEY—NEW GUINEA
Bird of Paradise Service, by D.C3 Airliner . . . Sydney—Northern Queensland Airports—New Guinea—Rabaul.

● INLAND SERVICES
Brisbane—Western Queensland Airports—Darwin, by Douglas Airliner.

● ISLAND SERVICES
Sydney—Norfolk Island, Sydney—Noumea—Suva.
Sydney—Lord Howe Island.

● SYDNEY—AUCKLAND
Trans-Tasman Service (with T.E.A.L.)

*Full details from leading travel agents, or*

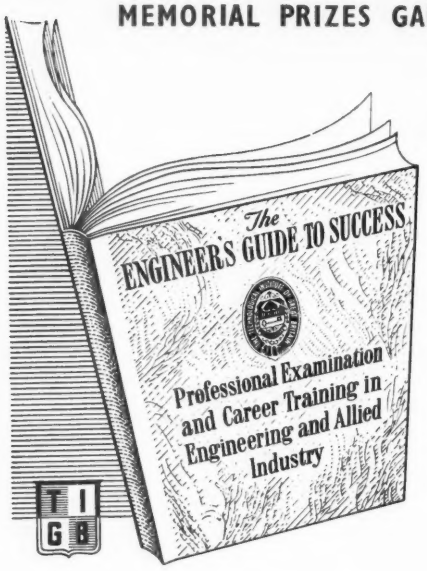
## Q·E·A and B·O·A·C

*QANTAS EMPIRE AIRWAYS in parallel with BRITISH OVERSEAS AIRWAYS CORPORATION*

E.2.

# 43 PLACES & 3 BADEN POWELL

## MEMORIAL PRIZES GAINED IN R.Ae.S. EXAMINATIONS




by home-study students of The T.I.G.B. furnish satisfactory proof that The T.I.G.B. courses are an authoritative means of equipping men in the aeronautics industry with technological knowledge.

You can start any time on a T.I.G.B. professional course for the A.F.R.Ae.S., A.M.I. Mech.E., A.M.I.E.E., or other institutional examination in which you are interested; but the best time is NOW, because Government and industry both require recognised technological attainment to be in the possession of those who aspire to higher posts. Write today to The T.I.G.B. for "The Engineer's Guide to Success," giving particulars of your technological and qualification requirements.

***The Professional Engineering and Aeronautics Tutors***

**THE TECHNOLOGICAL INSTITUTE OF GREAT BRITAIN**

**39 Temple Bar House, London, EC4**

---

# DATA SHEETS

on

## AERODYNAMICS and STRESSED SKIN STRUCTURES

For Use in Aeronautical Design
and
Drawing Offices

*Write for full particulars to:—*

The Secretary
THE ROYAL AERONAUTICAL SOCIETY
4 Hamilton Place, London, W.1. Grosvenor 3515

DH
ACHIEVEMENT
IN JET PROPULSION
APRIL 1944 FIRST JET ENGINE TO EXCEED 500 MPH IN BOTH BRITAIN AND AMERICA.
JANUARY 1945 FIRST JET ENGINE TO OBTAIN MILITARY TYPE - APPROVAL.
MARCH 1948 WORLD'S ALTITUDE RECORD FOR AEROPLANES - 59,446 FT., 18119 M
APRIL 1948 WORLD'S SPEED RECORD FOR 100 K.M. CLOSED CIRCUIT - 605·23 M.P.H., 974·02 K.M. HR
JULY 1948 FIRST JET ENGINE TO MAKE THE ATLANTIC CROSSING.
JULY 1948 FIRST JET ENGINE TO OBTAIN APPROVAL FOR CIVIL PASSENGER SERVICES.
AUGUST 1948 SUCCESSFUL COMPLETION OF SEVEREST EVER 500-HR. ENGINE TEST.
DE HAVILLAND
JET ENGINES

# AIRWORK LIMITED *Charter Division . .*

The Contract Charter Division is yet another important section of the world-wide organisation of Airwork Limited. With its home base at Blackbushe Airport, Surrey, Airwork employs 48 aircraft; 66 seasoned pilots; 30 other crew as well as a team of efficient air hostesses. Backed by the organisation's own Repair and Maintenance sections—an advantage few firms can claim—it is able to provide all-in, self-contained service unrivalled for smoothness and dependability of operation.

Outcome of eighteen years' planned development, Airwork Charter Division forges yet another link in a progressively developed chain of closely inter-related services designed to appeal especially to all interested in long-term charter work.

## THE SERVICES OF AIRWORK

- Air Transport Contracting
- Servicing and Maintenance of Aircraft
- Sale and Purchase of Aircraft
- Hire and Fly-Yourself Service
- Contract Charter Flying
- Overhaul and Modification of Aircraft
- Operation and Management of Flying Schools and Clubs
- Specialised Aerodrome Catering

AIRWORK LIMITED · 15 CHESTERFIELD STREET · LONDON · W.1 · TEL: GROSVENOR 4841

*Also at: Gatwick Airport, Horley, Surrey. Blackbushe Airport, Nr. Camberley, Surrey. Langley Aerodrome, Bucks. Heston Airport, Middlesex. Loughborough Aerodrome, Dishley, Leics. Perth Aerodrome, Perthshire. Renfrew Airport, Renfrewshire.*

# BRANCHES OF THE ROYAL AERONAUTICAL SOCIETY

## AND THEIR SECRETARIES

**BELFAST BRANCH**
*Secretary*: J. C. CORLETT, A.R.Ae.S.
c/o Short Bros. & Harland Ltd.,
Queen's Island, Belfast.

**BIRMINGHAM BRANCH**
*Secretary*: C. P. HOMES, A.R.Ae.S.,
81 Peplins Way,
Kings Norton, Birmingham 30.

**BRISTOL BRANCH**
*Secretary*: B. P. LAIGHT, A.F.R.Ae.S.
c/o Bristol Aeroplane Co., A.D.D.O.,
Filton House, Bristol.

**BROUGH BRANCH**
*Secretary*: F. A. WILKINSON, A.F.R.Ae.S.,
c/o Blackburn Aircraft Ltd.,
Brough, E. Yorks.

**COVENTRY BRANCH**
*Secretary*: C. T. SCULTHORPE, A.F.R.Ae.S.,
c/o Design Dept.,
Sir W. G. Armstrong-Whitworth Aircraft Ltd.,
Baginton, Coventry.

**DERBY BRANCH**
*Secretary*: J. L. BATCHELOR, A.R.Ae.S.,
154 Littleover Lane, Derby.

**GLASGOW BRANCH**
*Secretary*: A. W. FRASER, A.R.Ae.S.,
39 West Crescent,
Muirhead, Troon, Ayrshire.

**GLOUCESTER & CHELTENHAM BRANCH**
*Secretary*: J. F. CUSS, A.F.R.Ae.S.,
c/o Gloster Aircraft Co. Ltd.,
Hucclecote, Glos.

**HATFIELD BRANCH**
*Secretary*: E. J. MANN, A.R.Ae.S.,
c/o de Havilland Aircraft Ltd.,
Hatfield, Herts.

**ISLE OF WIGHT BRANCH**
*Secretary*: M. J. BRENNAN, A.F.R.Ae.S.,
c/o Design Office, Saunders-Roe Ltd.,
Osborne, E. Cowes.

**LEICESTER BRANCH**
*Secretary*: F. WATKIN, A.F.R.Ae.S.,
c/o Auster Aircraft Ltd.,
Rearsby Aerodrome,
Rearsby, Leicester.

**LUTON BRANCH**
*Secretary*: P. A. DRILLIEN, A.R.Ae.S.,
c/o D. Napier & Son Ltd.,
Luton, Beds.

**MANCHESTER BRANCH**
*Secretary*: J. A. E. WATERFALL,
56 Manor Avenue,
Ashton-on-Mersey, Ches.

**PORTSMOUTH BRANCH**
*Secretary*: E. M. BELLAMY,
c/o Airspeed Ltd.,
The Airport, Portsmouth.

**PRESTON BRANCH**
*Secretary*: D. E. SMITH, O.B.E., B.A.,
c/o English Electric Co. Ltd., A.F.R.Ae.S.
Aircraft Division,
Warton Aerodrome,
Nr. Preston, Lancs.

**READING BRANCH**
*Secretary*: B. BUCK, A.F.R.Ae.S.,
" Newlands," Western Avenue,
Woodley, Reading.

**SOUTHAMPTON BRANCH**
*Secretary*: T. TANNER, A.F.R.Ae.S.,
University College,
Southampton.

**WEYBRIDGE BRANCH**
*Secretary*: J. H. SINCLAIR, A.R.Ae.S.,
Vickers-Armstrongs Ltd.,
Weybridge, Surrey.

**YEOVIL BRANCH**
*Secretary*: L. A. LANSDOWN, A.F.R.Ae.S.,
c/o Westland Aircraft Ltd.,
Yeovil, Som.

**AUSTRALIAN BRANCH**
*Secretary*: W. ISBISTER, A.F.R.Ae.S.,
Science House,
Gloucester & Essex Street,
Sydney, N.S.W.

**CANADA BRANCH**
**Montreal**
Engineering Institute of Canada,
2050, Mansfield Street,
Montreal.

**Ottawa**
*Secretary*: M. S. KUHRING, A.R.Ae.S.,
National Research Council,
Aeronautical Laboratory,
Ottawa.

**NEW ZEALAND BRANCH**
*Secretary*: T. T. N. COLERIDGE, A.F.R.Ae.S.,
c/o The Shell Co. of N.Z. Ltd.,
P.O. Box 1663,
Wellington, New Zealand.

**SOUTH AFRICA BRANCH**
*Secretary*: MAJOR E. MALLINSON, A.F.R.Ae.S.,
P.O. Box 43, Lyttelton,
Pretoria District, Transvaal.

792A

# THE NEW TYPE 170 FREIGHTER

Design and power unit improvements now incorporated enable the "Bristol" NEW Type 170 to carry more freight . . . further . . . faster and cheaper. Today the operator has at his disposal a payload maximum of nearly 5 tons—and a maximum range of 1,500 miles. These advantages, with their direct and favourable influence on the earning capacity of the aircraft establish the "Bristol" NEW Type 170 as the soundest commercial aeroplane proposition available today.

A fully comprehensive brochure will be sent, on request, to interested executives.

THE *Bristol* AEROPLANE COMPANY LIMITED · ENGLAND

# The Charter of Incorporation

for

# The Royal Aeronautical Society

# A MESSAGE FROM THE PRESIDENT

HIS MAJESTY THE KING has granted to the Royal Aeronautical Society a Charter of Incorporation. The Charter itself, bearing the imprint of the Great Seal, lies in the safe at No. 4 Hamilton Place. A copy of the text of this historic document follows these notes. Henceforward, as the text states, the Royal Aeronautical Society is "one Body Corporate and Politic," and it has power to do all things which are "incidental or appertaining to a Body Corporate." It will no longer be necessary for the company Aerial Science Ltd., which has for so long carried on the financial affairs of the Royal Aeronautical Society, to exist. A Body Corporate can enter into contracts, sue in Courts, and do business on its own account. So that the granting of the Charter, besides being an honour to be proud of, is, at the same time, a convenience to enjoy.

In medieval times Charters were common and the idea behind them was generally understood. To-day the granting of a Charter has an attractive antique air and is frequently thought to represent no more than the maintenance of an attractive custom. There is, however, more in it than that. There is always a distinction to be drawn between a body which sets itself up to perform a given task and a body which is appointed by high authority to do that task. When the high authority is the highest authority of all there is no doubt that the status of the latter body is imcomparably higher than that of the former. In the case of our Society, the position is that in 1866 a number of men set themselves up to advance the frontiers of aeronautical knowledge. The Society continued as a self-appointed body until this present time. Now it has pleased His Majesty to appoint the Royal Aeronautical Society to the task of the general advancement of Aeronautical Art, Science and Engineering and in his Realm he has appointed no others to this same task. We become *de jure*, what we have, I hope, long been *de facto*, the acknowledged British authority for "promoting that species of knowledge which distinguishes the profession of Aeronautics." We are in a proud position, and take our place with a number of other ancient and modern societies of high esteem to whom the King has similarly granted incorporation.

His Majesty has twice greatly honoured this Society. In 1922 while Duke of York he became its Patron, and has remained its Patron ever since. Now he grants us a Royal Charter. This is a distinction which I believe the Society, which in the last few years has been so clearly growing in strength and in influence, can carry with dignity, responsibility and gratitude to its Patron. Membership of the Royal Aeronautical Society has long been for each of us a privilege and a high qualification. From now on we can regard it, in addition, as an honour and a seal on our professional standing.

# THE CHARTER

## AT THE COURT AT BUCKINGHAM PALACE

**The 22nd day of December, 1948**

PRESENT,

**THE KING'S MOST EXCELLENT MAJESTY**

**IN COUNCIL**

WHEREAS there was this day read at the Board a Report of a Committee of the Lords of His Majesty's Most Honourable Privy Council, dated the 8th day of December, 1948, in the words following, viz.:—

"YOUR MAJESTY having been pleased, by Your Order of the 2nd day of June, 1948, to refer unto this Committee the humble Petition of H. Roxbee Cox, Esquire, and others, praying for the grant of a Charter of Incorporation to the Royal Aeronautical Society.

"THE LORDS OF THE COMMITTEE, in obedience to Your Majesty's said Order of Reference, have taken the said Petition into consideration, and do this day agree humbly to report, as their opinion, to Your Majesty, that a Charter may be granted by Your Majesty in terms of the Draft hereunto annexed."

HIS MAJESTY having taken into consideration the said Report, and the Draft Charter accompanying it, was pleased, by and with the advice of His Privy Council, to approve thereof, and to order, as it is hereby ordered, that the Right Honourable James Chuter Ede, one of His Majesty's Principal Secretaries of State, do cause a Warrant to be prepared for His Majesty's Royal Signature, for passing under the Great Seal a Charter in conformity with the said Draft, which is hereunto annexed.

*E. C. E. Leadbitter.*

**George the Sixth** by the Grace of God, of Great Britain, Ireland and the British Dominions beyond the Seas King, Defender of the Faith:

To all to whom these Presents shall come, Greeting:

**Whereas** the unincorporated Association commonly known as the Royal Aeronautical Society have petitioned Us for a Charter of Incorporation such as in and by these Presents granted.

**And whereas We** are minded to comply with the prayer of such Petition:

NOW THEREFORE WE by virtue of Our Royal Prerogative in that behalf and of all others powers enabling Us so to do of Our special grace certain knowledge and mere motion do hereby for Us Our Heirs and Successors will grant direct appoint and declare as follows:

1. The persons now members of the said Association and all such persons as may hereafter become members of the Body Corporate or Corporation hereby constituted pursuant to or by virtue of the powers granted by these Presents and their successors shall for ever hereafter (so long as they shall continue to be such

members) be by virtue of these Presents one Body Corporate and Politic by the name of the "Royal Aeronautical Society with which is incorporated the Institution of Aeronautical Engineers" and by the same name shall have perpetual succession and a Common Seal with power to break alter and make anew the said Seal from time to time at their will and pleasure and by the same name shall and may sue and be sued in all Courts and in all manner of actions and suits and shall have power to do all other matters and things incidental or appertaining to a Body Corporate.

2. We do also hereby for Us Our Heirs and Successors license authorise and for ever hereafter enable the Body hereby incorporated (hereinafter called "the Society") or any persons or person on its behalf to acquire for the purposes of the Society any lands tenements or hereditaments or any interest in any lands tenements or hereditaments whatsoever within Our United Kingdom of Great Britain and Northern Ireland not exceeding in the whole the annual value of ten thousand pounds (to be determined according to the value thereof at the time when the same are respectively acquired) in addition to the leasehold premises Nos. 4, 8 and 9 Hamilton Place, Park Lane, W.1 and to hold the same in perpetuity or otherwise and from time to time (subject to all such consents as are by law required) to grant demise alienate or otherwise dispose of the same or any part thereof.

3. And We do also hereby for Us Our Heirs and Successors give and grant Our Licence to any person and any Body Politic or Corporate to assure in perpetuity or otherwise or to demise or devise to or for the benefit of the Society any lands tenements or hereditaments whatsoever or any interest in any lands tenements or hereditaments within Our United Kingdom of Great Britain and Northern Ireland so as the same do not exceed at any one time the annual value aforesaid; hereby nevertheless declaring that it shall not be incumbent upon any such person or persons or Body to inquire as to the annual value of the property which may have been previously acquired by the Society.

4. The objects and purposes for which the Society is hereby constituted are the general advancement of Aeronautical Art, Science and Engineering and more particularly for promoting that species of knowledge which distinguishes the profession of Aeronautics and for those purposes *inter alia*.

(*a*) to facilitate the exchange of information and ideas amongst the members of the Society and others,

(*b*) to hold meetings of the Society for reading and discussing communications and lectures bearing upon Aeronautical Art, Science and Engineering (and upon subjects relating thereto),

(*c*) to hold or promote Exhibitions,

(*d*) to establish, form and maintain libraries and collections of models, designs, drawings and other articles of interest in connection with the development and improvement of Aeronautical Art, Science and Engineering,

(*e*) to print publish sell lend and distribute any communications made to the Society or any similar Society and the reports of the proceedings or transactions of the Society or any similar Society and to purchase reproduce print publish and distribute any other papers communications books works or treatises relating to Aeronautical Art, Science or Engineering or any abstracts thereof or extracts therefrom and for this purpose to cause translations to be made into or from any language of any such communications reports papers books works or treatises.

(*f*) to encourage invention and research,

(*g*) to establish sections and branches of the Society in the British Commonwealth,

(*h*) to provide and award medals and prizes for contributions to the advancement of Aeronautical Art, Science and Engineering,

(*i*) to give the Legislature and any departments thereof and public bodies and engineering institutions and others, facilities for conferring with and

ascertaining the views of members of the Society and other persons engaged in the profession of aeronautics as regards matters directly or indirectly affecting Aeronautical Art, Science and Engineering and to petition, confer, send representatives to and communicate with all or any such authorities and bodies in regard to the same,

(*j*) to establish, subsidise, promote, co-operate with, manage, superintend, lend monetary assistance to or otherwise assist any associations, incorporated or not incorporated, with objects altogether or in part similar to those of the Society, provided that such associations prohibit the payment of any dividend or profit to or the distribution of any property amongst their members as strictly as such payment or distribution is prohibited to or amongst the members of the Society,

(*k*) to found, establish, undertake, superintend, administer and contribute to any educational, art and technical schools and classes and institutions, and any charitable or benevolent funds from whence salaries or remuneration may be paid, or donations or advances made to teachers, masters and deserving persons who may be engaged in educational or art and technical work, or may have been engaged in the profession of aeronautics or connected with any person engaged therein, and to subscribe to, contribute to or otherwise assist any charitable or benevolent institutions or undertakings connected with the said profession,

(*l*) to do all other things incidental or conducive to the attainment of the Society's objects.

5. The income and property of the Society shall be applied solely towards the promotion of the objects of the Society. The Society shall not carry on any trade or business or engage in any transaction with a view to the pecuniary gain or profit of the members thereof.

6. The members of the Society shall not have any personal claim on any property of the Society and no portion of the income or property of the Society shall be paid or transferred directly or indirectly by way of dividend bonus or otherwise howsoever by way of profit to persons who at any time are or have been members of the Society or to any of them provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officer or servant of the Society in return for any services rendered to the Society.

7. Unless and until the By-laws of the Society shall otherwise provide there shall be seven classes of members of the Society termed respectively Founder Members, Fellows, Associate Fellows, Associates, Companions, Graduates and Students and hereinafter referred to as members. Such classes shall have the rights and privileges including the privilege of Honorary titles and obligations set out in the By-laws. The Founder Members, Fellows, Associate Fellows and Associates are herein and in the said By-laws collectively referred to as Voters. The members may be of either sex. The persons now members of the existing Society shall be deemed to have entered the Society in the class to which they belonged in the existing Society. Companies, corporations and associations may subject to the By-laws be admitted as non-voting members.

8. The qualifications method and terms of admission privileges and obligations including liability to expulsion or suspension of members of each of the said classes respectively shall be such as the By-laws for the time being shall direct. The power of election of each person seeking admission to any class of membership shall be vested in the Council (as hereinafter defined) whose responsibility it shall be to decide whether he has or has not fulfilled such conditions as are applicable to his case.

9. The meetings of the Society shall be of such classes and shall be held for such purposes and the members of the Society shall have such respective rights of attending and in the case of Voters of voting at such meetings and such other rights and privileges as may be prescribed by the By-laws of the Society.

10. There shall be a Council of the Society consisting of such number of members with such qualifications and to be elected or constituted as such members of Council in such manner and to hold office for such period and on such terms to seek re-election and otherwise as the By-laws for the time being shall direct.

11. The first members of the Council of the Society shall be the members of the Council of the existing Society namely H. Roxbee Cox, Esq., Ph.D., D.I.C., President; Sir Frederick Handley Page, C.B.E. and Sir A. H. Roy Fedden, M.B.E., D.Sc., Past Presidents; Sir John S. Buchanan, C.B.E., W. G. A. Perring, Esq. and N. E. Rowe, Esq., C.B.E., B.Sc., D.I.C., Vice Presidents; and L. Aitchison, Esq., D.Met., B.Sc., E. J. N. Archbold, Esq., B.Sc., The Rt. Hon. the Lord Brabazon of Tara, M.C., G. P. Bulman, Esq., C.B.E., B.Sc., S. Camm, Esq., C.B.E., A. V. Cleaver, Esq., G. P. Douglas, Esq., O.B.E., M.C., D.Sc., A. G. Elliott, Esq., C.B.E., W. S. Farren, Esq., C.B., M.B.E., M.A., F.R.S., A. A. Hall, Esq., M.A., S. Scott Hall, Esq., M.Sc., D.I.C., J. W. F. Housego, Esq., E. T. Jones, Esq., O.B.E., M.Eng., Sir Ben Lockspeiser, M.A., P. G. Masefield, Esq., M.A., W. Tye, Esq., B.Sc., C. F. Uwins, Esq., O.B.E., A.F.C., and H. C. Watts, Esq., M.B.E., D.Sc. The first Secretary of the Society shall be J. Laurence Pritchard, Esq. The said members of the Council shall respectively hold office as such until the due election and coming into office of their successors in accordance with the By-laws but shall be respectively eligible subject to the By-laws for re-election if otherwise qualified.

12. The direction and management of the Society and its affairs and business shall be vested in the Council subject to the provisions of these Presents and to the By-laws of the Society. The business of the Council shall be conducted in such manner as the Council may from time to time prescribe.

13. The Society shall have such Officers with such functions tenure and terms of office as the By-laws may prescribe and such other officers and servants as the Council of the Society may from time to time appoint.

14. The power to make such By-laws of the Society as shall seem to them requisite and convenient for the regulation government and advantage of the Society its Members and property and for the furtherance of the objects and purposes of the Society, and from time to time to revoke alter or amend any By-law or By-laws theretofore made, but so that the same be not repugnant to these Presents or to the Laws and Statutes of this Our Realm, shall be vested in the voters of the Society. Such power shall be exercised in General Meetings of Voters with respect to which not less than 21 days' notice in writing has been given of the matters to be taken into consideration thereat and otherwise held in accordance with the By-laws or in the case of the first By-laws at a Special General Meeting convened and held in accordance with the Rules of the existing Society. Provided that no such By-law revocation alteration or amendment shall take effect until the same has been allowed by the Lords of Our Privy Council of which allowance a Certificate under the hand of the Clerk of Our Privy Council shall be conclusive evidence.

15. The first By-laws to be made under these Presents shall be made by the Voters of the Society within the period of six months from the date of these Presents unless the Lords of Our Privy Council shall see fit to extend such period of which extension the Certificate of the Clerk of Our Privy Council shall be conclusive evidence.

16. Pending the making and approval of the By-laws to be made under these Presents but no longer the Rules of the existing Society shall be the By-laws of the Society so far as the same may be applicable and shall have effect as though the Society its Officers and Members had therein been referred to throughout in lieu of the existing Society its Officers and Members.

17. The property and moneys of the existing Society including any property and moneys held on behalf of or in trust for the existing Society by any person or persons or body politic or corporate other than property and moneys held by Aerial Science Limited and by Aeronautical Trusts Limited shall from the date of these Presents become and be deemed to be the property and moneys of the

Society and shall as soon as may be be formally transferred to the Society or such person or persons on its behalf as the By-laws may prescribe. The Society shall as soon as may be procure that Aerial Science Limited be wound up and that its surplus assets be transferred in specie to the Society or such person or persons as aforesaid on its behalf. All property and moneys vested in or held by Aeronautical Trusts Limited as a trustee for the existing Society shall continue to be vested in or held by that Company as a trustee for the Society unless and until the Society shall otherwise determine.

18. In the investment of moneys belonging to or held by the Society and applicable for the general purposes of the Society the Society shall not be limited to investments normally known as trustee securities but may invest such moneys in such manner and upon such investments or securities including (subject to the limits hereinbefore imposed) the purchase of freehold or leasehold land as it might do if it were absolute beneficial owner thereof. PROVIDED ALWAYS that it shall not invest money upon any Bonds, Debentures, Debenture Stock, Notes or other obligations, Guaranteed, Preference, Preferred or Preferred Ordinary Stocks or Shares of any Company unless dividends at the rate of at least four per cent. per annum have been paid for five consecutive years immediately prior to the time of investment on the Ordinary Deferred or Deferred Ordinary Stock or Shares of the Company. PROVIDED ALSO that it shall not invest money upon Ordinary Deferred or Deferred Ordinary Stocks and Shares unless dividends of at least four per cent. per annum have been paid thereon for five consecutive years immediately prior to the time of investment. PROVIDED ALSO that it shall not make any investment unless first advised by a stockbroker or firm of stockbrokers of not less than 20 years' standing that the same is an investment on which they would be prepared to advise a client of theirs (not being a trustee) to lay out his own money and subject as aforesaid no liability shall attach to any officer servant or member of the Society in respect of any loss or depreciation of any investment so made as aforesaid and any investment may be varied from time to time at the discretion of the Society.

19. The Council may by a resolution in that behalf passed at any meeting by a majority of not less than two-thirds of the members of the Council present and voting (being an absolute majority of the whole numbers of the members of the Council) and confirmed at a Special General Meeting of the Voters of the Society duly convened and held not less than one month or more than four months after the date of such meeting of the Council by a majority of not less than two-thirds of the Voters present and voting alter amend or add to these Presents and such alterations amendment or additions shall when allowed by Us in Council become effectual so that these Presents shall thenceforward continue and operate as though they had been originally granted and made accordingly. This provision shall apply to these Presents as altered amended or added to in manner aforesaid.

20. And We do hereby for Us Our Heirs and Successors Grant and Declare that these Our Letters Patent or the enrolment or exemplification thereof shall be in all things good firm valid and effectual according to the true intent and meaning of the same and shall be taken construed and adjudged in all Our Courts and elsewhere in the most favourable and beneficial sense and for the best advantage of the Society any mis-recital non-recital omission defect imperfection matter or thing whatsoever notwithstanding.

**In Witness** whereof We have caused these Our Letters to be made Patent.

**Witness** Ourself at Westminster this *Seventeenth* day of *January* in the *Thirteenth* year of Our Reign.

**By Warrant** under the King's Sign Manual.

*NAPIER*

# FRENCH TURBO-PROPELLER AND TURBO-REACTION ENGINES

by

P. DESTIVAL

*(Read by R. A. Bidard, Chief Engineer, Cie Eléctro-Mécanique.)*

WHEN, in the course of his visit to Paris in May 1948, Dr. Roxbee Cox invited me to lecture to the Royal Aeronautical Society on our work in the field of turbo-propeller and turbo-reaction engines, I was torn between two sentiments; the great honour which was done to me, and the seeming temerity for a French engineer to discourse on aircraft turbines before some of the people who had been responsible for the W2 700, the Nene, Ghost, F2, Theseus, Mamba, and other engines. The first of these sentiments however carried the day, as it could hardly fail to do in view of Dr. Roxbee Cox's extreme kindness.

Therefore I ask for the indulgence of my audience in listening to this, the first account to be given of the modest work done since 1941 by a team of French technicians, who were specialists in steam and industrial gas turbines, who had foreseen the possible development of the latter for aircraft, and who, completely cut off from the engineering world during the Occupation, at first worked literally in complete isolation, unaware even of the existence of the British and German achievements. I should stress that this refers only to the efforts of the SOCEMA* under licence from the Cie Eléctro-Mécanique; aircraft turbines have also been designed and made by other French firms.

The idea of applying the gas turbine to aircraft occurred to us well before the last war; we thought of it however more particularly as a turbo-propeller unit, and we were not the only ones to take that view, as is shown by the many patents taken out in that field. The real problem was to know what specific weight could be reached, and from this point of view the early industrial gas turbines were hardly encouraging; we should almost have preferred not to know them.

In 1941 we undertook a turbo-propeller engine project with the agreement and help of the Service Technique du Ministère de l'Air, which at that time was in the Free Zone. Our project was designated the TGA, which could either stand for Aircraft Gas Turbine or Railcar Turbo-Unit ("Turbo-Groupe d'Autorail"), the second version being intended to deceive the Occupiers in case they came across our work. To make the latter denomination more plausible, the contract was placed under cover of the French Railway Authority.

From the start we adopted the form which our engine still has, namely axial compressor, annular combustion chamber without change of direction of the air flow, and turbine. This relative layout of the main elements, although

The 755th Lecture read before the Society—on 11th November 1948, at the Institution of Civil Engineers, Great George Street, London, S.W.1. In the Chair, the President, Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., F.I.Ae.S.

M. Destival is head of the technical department working on gas turbines at the Cie Eléctro-Mécanique. He was unable to attend the Lecture because of illness.

* Société d'Etude de Materiels d'Aviation, a subsidiary company of Cie Eléctro-Mécanique.

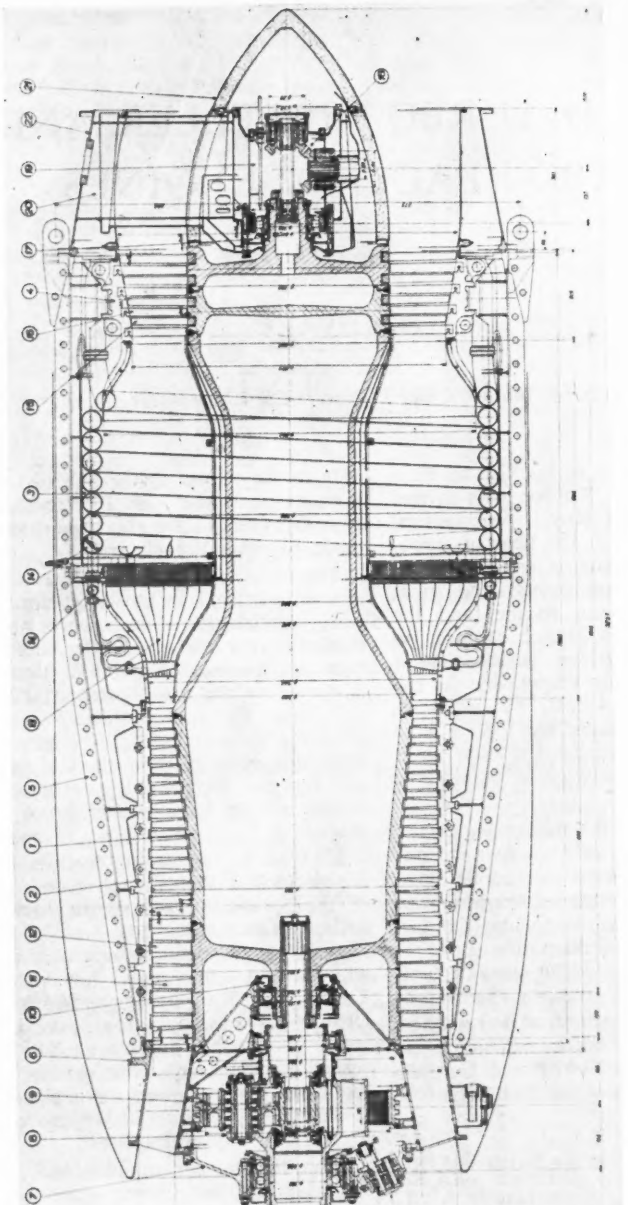


Fig. 1.

TGA-1 bis. General arrangement of vaporisation type.

Note the 15-stage compressor, the 4-stage turbine, the vaporisation chamber, the epicyclic reduction gear inside the air entry, the auxiliaries drive by the rear bearing. The whole of the machine is mounted in a sheet metal shell with a joint in the diametral vertical plane.

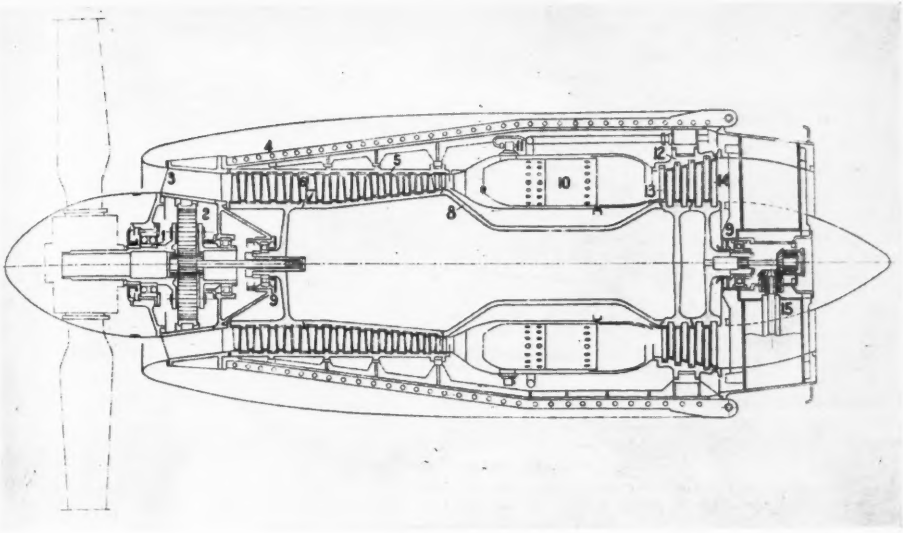



Fig. 2.
TGA-1 bis. Diagrammatic section of atomisation type.

1. Thrust bearing of propeller.
2. Reduction gear of propeller.
3. Air intake.
4. Engine casing.
5. Cylinder of compressor.
6. Fixed blades of compressor.
7. Moving blades of compressor.
8. Rotor.
9. Rotor bearings.
10. Combustion chambers.
11. Fuel injector.
12. Turbine cylinder.
13. Fixed blades of turbine.
14. Moving blades of turbine.
15. Control of starter and auxiliaries.

All the elements of the machine are identical with those of Fig. 1, except for the combustion chamber in which the coil and burners have been replaced by 10 flame tubes.

orthodox to-day, was not so orthodox before the war, and was the object of a Brown Boveri patent dated June 1939. Likewise, we chose a cycle (*i.e.* a compression ratio and a value of temperature ahead of the turbine) on which we could rely from the point of view of efficiency and turbine behaviour, but which was based on pre-war technique and materials. The lightened construction and the enhanced combustion problems involved enough novelty and difficulties in store to make us conservative towards the cycle, which was characterised by a compression ratio of 3.6 and a temperature ahead of the turbine of 550°C. (1,022°F.) at cruising and 600°C. (1,112°F.) at maximum power.

To make sure of the practicability of our project we took on as consultant a well-known airframe designer, M. Girodin, who was responsible for the Amiot 351, and who worked out an aircraft project concurrently with our first turbo-propeller engine design. The latter was due to give a total cruising power of 3,000 h.p. at sea level. The fuel consumption was bound to be high in view of the conservative cycle adopted, and was to be 0.78 lb./h.p.-hour at sea level and 310 m.p.h., and 0.56 lb./h.p.-hour at 32,800 ft., and the same speed. The designed weight was 4,960 lb. (the actual weight is 4,630 lb.) and the maximum diameter 45.3 in.

With these characteristics the aircraft project, which was fitted with two engines, was to lead to a machine of 53,000 lb. take-off weight, of which the payload accounted for 7,500 lb., and was to have a range of 1,060 miles at sea level at a speed of 310 m.p.h., the range increasing to 1,800 miles at 16,400 ft. and 2,860 miles at 32,800 ft. This, we were told, was as good as, if not better than, could be obtained with the engines of the time, and hence encouraging enough to make us adhere to the project as it was;

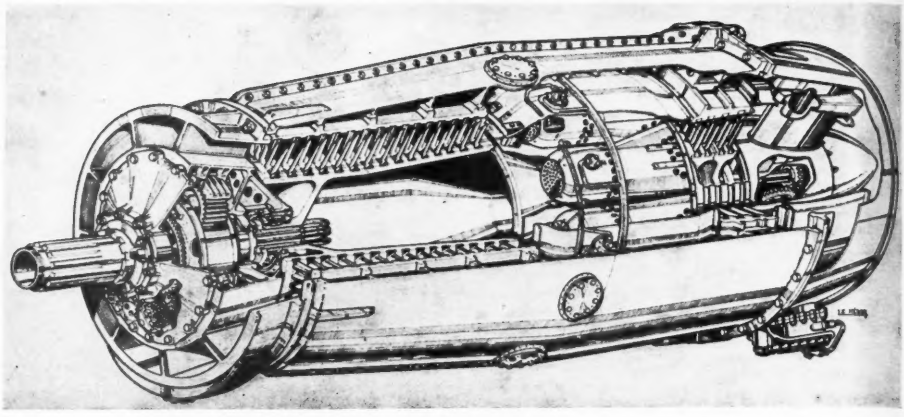


Fig. 3.
TGA-1 bis. Perspective view (atomisation type).
Note from left to right the propeller shaft, the epicyclic reduction gear, the 15-stage compressor, the chamber with 10 flame tubes, the 4-stage turbine, the rear bearing and, below, the starter drive and auxiliaries drive shaft end.

when Parsons launched the Turbinia in the early days of the steam turbine, the latter compared less favourably with the piston steam engine. The performance obtained, which was equivalent to that given by an orthodox engine in spite of a greater weight and specific fuel consumption, was due to the reduction of frontal area and the absence of cooling.

The first characteristics aimed at for our turbo-propeller were simplicity and ease of manufacture, even at the expense of performance. Indeed it was obvious in 1941 that if the unit was to be made at all, it would have to be made in a difficult industrial climate. These considerations led us to provide a single rotor for the compressor and turbine, carried by only two bearings, and made up of welded drum elements, according to a technique with which we were familiar.

The compressor has 15 stages for a compression ratio of 3.6; this means a rise of temperature of only 10.5°C. (18.9°F.) per stage; that is a figure that one hardly dares quote nowadays, but in the state of the art of compressors before the war it was fair enough. I recall that the RAE Freda compressor used on the Metrovick F2 gave 19°C. (34.2°F.) per stage and that the latest compressors can reach 30°C. (54°F.), according to Mr. H. Constant; this is a measure of the progress accomplished under the impetus of the requirements of aviation, but it also gives an idea of the difficulty of designing a turbo-propeller engine with pre-war compressors.

The type of compressor of which we had some experience and knew the high efficiency was one with 50 per cent. reaction, Mach number 0.6 and blade angle of about 45°. These characteristics however only gave us an axial speed of about 250 ft./sec., and hence an unacceptably large diameter at the compressor entry, the whole engine being determined, with the layout chosen, by the dimensions of the first compressor stage. With the object of increasing the axial velocity as well as the specific work per stage, we chose a reaction percentage of nearly 100 for the first stage, *i.e.* an axial entry into the first moving row, which meant a Mach number of 0.9 at the tips of the moving blades. To get away quickly from this alarming figure we then adopted decreasing reaction percentages for the following stages, going down to 50 per cent. at the seventh stage, with an axial velocity decreasing from 426 to 246 ft./sec.

This unusual method of compressor determination had two advantages; first, the moving stages had a grid with constant geometric characteristics, which was an advantage at the time for we did not have that accurate knowledge of grids in all their

forms which can now be obtained from research work such as that of Mr. A. R. Howell; secondly, because we wanted to get at the seventh stage a reaction of 50 per cent. at all diameters and therefore a rotational movement, the resulting progressive increase in the overall rotation of the air flow avoided variations of axial velocity and their resulting secondary accelerations, which are now the cause of so much controversy and of a flood of literature. Lastly, in spite of this apparent complication of the compressor, the blading required but two types of profile.

All these explanations are of historical interest only, but they indicate the unorthodox form of the compressor, which incidentally turned out to be quite satisfactory, since the calculated output and compression ratio were reached with an efficiency of over 85 per cent., which was higher than the calculated figure. We were rather circumspect in complimenting ourselves on this result, since there were various difficulties during manufacture which compelled us to give generous concessions on the accuracy of the blading. If the blading had been exactly as we wanted it, the agreement between results and calculations might not have been so good.

When we came to accommodating the 15 compressor stages and four turbine stages (to which we shall refer later) on a single rotor, there was a great temptation to use a high aspect ratio for the blades, at least in the first stages, which would have shortened the engine advantageously. We were able to resist the temptation and not to exceed an aspect ratio of three for the first stages, which corresponded to a value of four for the ratio of the vibration frequencies to the speed of the shaft. This aspect ratio was further decreased in later prototypes.

For the first stages of a compressor the bending and centrifugal stresses generally allow quite high aspect ratios, and the latter are limited mainly by considerations of vibration frequency. For a given profile and for compressors of any size, but of similar tangential velocities, the ratio of the natural frequency of the blade to the angular velocity

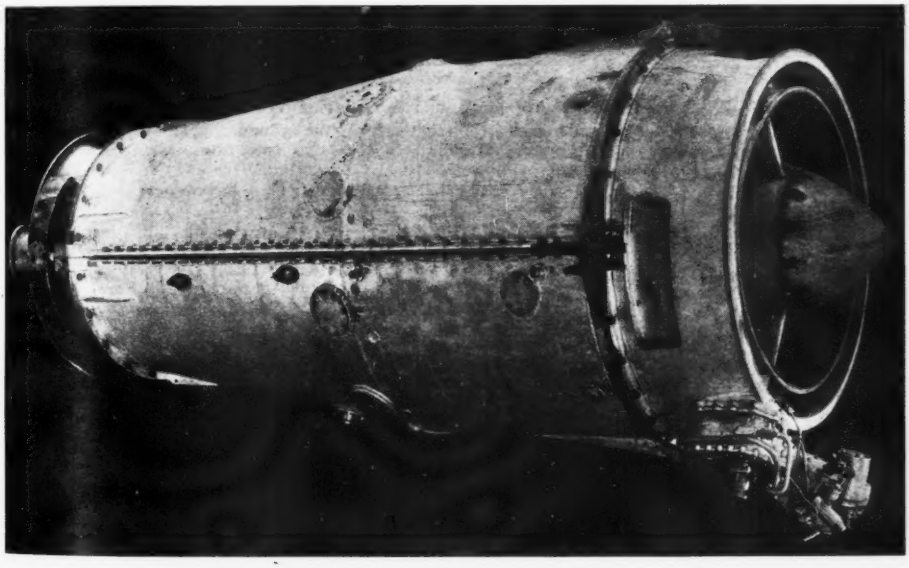


Fig. 4.
TGA-1 bis. External view.
Turbo-propeller engine TGA-1 bis, designed in 1941, built after the war. Power 3,000 h.p., weight 4,400 lb., maximum diameter 45 in. Note the attachment lugs at the rear of the shell, the starter dogs and the end of the auxiliaries drive shaft; the auxiliaries are gathered into a compact group which is designed to be located near the engine in the wing leading edge.

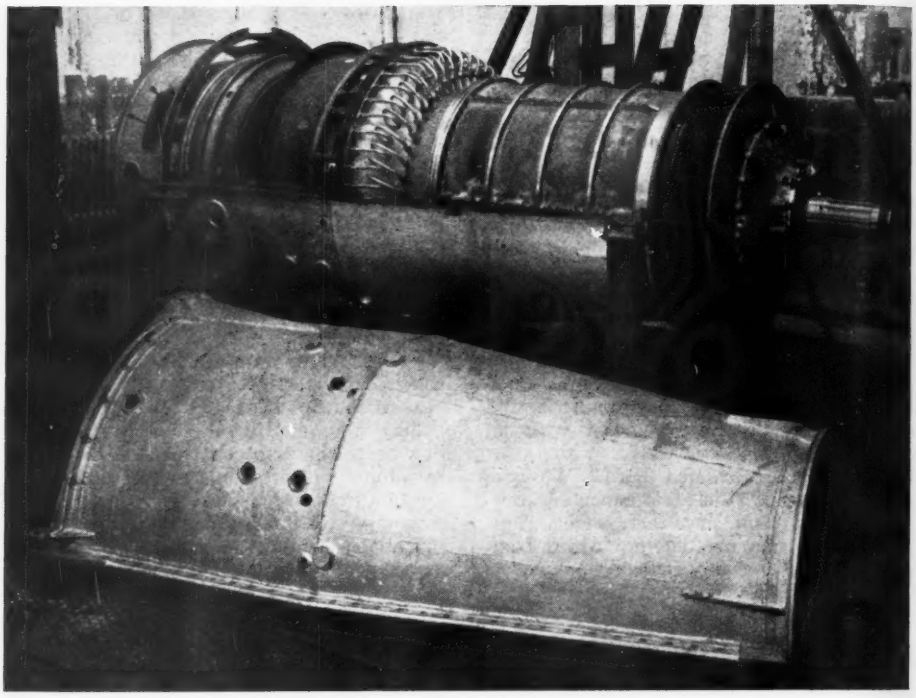


Fig. 5.

TGA-1 bis. Front view, upper casing removed (vaporisation type).

Note from right to left the propeller shaft, the front face of the reduction gear, the air entry, the compressor cylinder, the vaporised fuel collectors, the outer combustion chamber shell, the turbine cylinder and the rear bearing.

of the rotor shaft depends only on the blade aspect ratio. Thus the value of the frequency ratio is easily seen just by looking at a compressor.

Some designers who have adopted high aspect ratios think no doubt that if the frequency ratio lies between say, two and three the blade is not more—perhaps even less—likely to vibrate than if it lies between four and five. That is not our view. Indeed we think that during the course of its working life, and particularly if its working speed is not constant, a turbine must necessarily pass through speed ranges in which blade vibrations are excited and fractures appear, sometimes only after a few thousand hours, a duration which will certainly have to be reached some time with aircraft turbines.

The probability of exciting vibrations up to a dangerous strain is less for a high frequency than for a low frequency blade, the most violent excitation phenomena being usually at rotation frequency or a low multiple thereof. In any event we have there a thorny problem, which Mr. Constant rightly stressed in a lecture to the Institution of Mechanical Engineers in 1945.

The first stages of the compressor were in steel and the last ones in light metal. In modern turbo engines the contrary is the general practice, because of the high temperature reached at the end with high compression ratio compressors. This did not apply in our case, and we chose light alloy blades for the last moving rows in order to lower the centrifugal stresses of the drum in that section; we adhered to steel for the first stages in order to resist erosion and also because we mistrusted the fatigue strength of light alloys. The blades are fixed

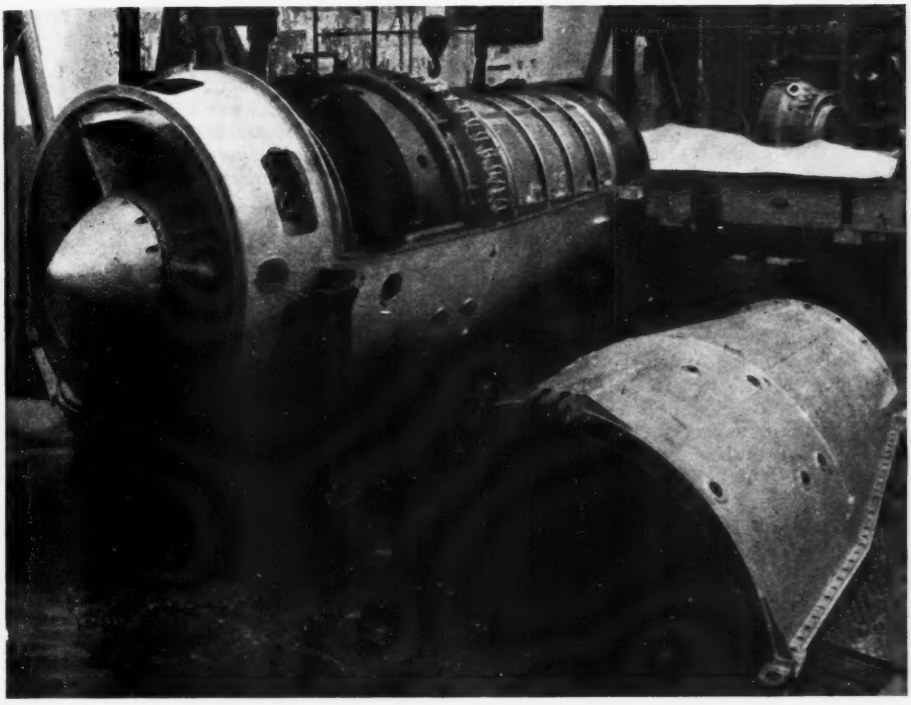


Fig. 6.

TGA-1 bis. Rear view, upper casing removed (vaporisation type).
Note from left to right the rear bearing, the combustion chamber, the vaporised fuel collectors, the compressor cylinder.

by a milled dovetail on a flat foot forged integrally with them. It is interesting that this method of attachment has been simultaneously adopted by most manufacturers in the various countries which have gone in for aircraft turbines with axial compressors, who cannot have been inspired by each other. In our case this construction was particularly advantageous, as the blades were mounted on a drum the thickness of which had to be kept down to a minimum. Our blades were actually stamped, but with generous excess thickness and then milled. Nowadays they would be stamped to size or cast.

Before any other characteristic, the turbine mounted on the same rotor as the compressor had to have that of accurately balancing the latter's axial thrust, no balancing piston being fitted; this requirement determined the diameter and hence the number of stages, which worked out at four. It is curious that among present-day units the number of turbine stages varies from one for the TG 100 (in spite of its high compression ratio) to four for the Handy and the TGA-1 bis. It is obvious that doubling the tangential velocity allows four times the pressure drop, and gives the advantage that the moving blades work at a lower temperature. But their centrifugal stress is higher and their carrier disc heavier. Moreover, although expansion phenomena can stand higher Mach numbers than compression phenomena, very high turbine speeds are not favourable to high efficiency. Furthermore, for turbines which have a large diameter and therefore a low blade height, losses in radial clearance become more important.

In a recent turbo-propeller project where the turbine diameter was not determined by the compressor balancing condition, as it was in the TGA-1 bis, we did a design with a four-stage turbine and another with a two-stage one, other things being equal. We found that both schemes had the same weight, and thus had no compunction in choosing the former, which had our preference *a priori*, particularly from the point of view of efficiency, which is so important in a turbo-propeller.

The turbine blading was treated like the low pressure blading of a steam turbine, *i.e.* it had high aspect ratio blades fitted with vibration damping threads; the latter give a quite acceptable loss in a turbine, although evidently not in a compressor.

With the diameter set by the compressor thrust balancing condition, it would have been possible to limit the number of stages to three. We chose four in order to get near to a reaction percentage of 50 at the mean diameter and not go below 15 at the inside diameter, this of course still being in order to obtain the optimum efficiency; with the cycle chosen, a gain of one per cent. in turbine efficiency means nearly four per cent. gain in useful power and consumption. We did not aim at a reaction percentage constant at all diameters, as is the fairly general practice with steam turbines, since with the low number of stages as compared with the latter, and the high value of blade height in relation to diameter, we feared the effects of non-conservation of irrotational movement, *i.e.* the appearance of non-recuperable turbulence in the meridian plane. Therefore we designed for an almost irrotational flow, with a slight correction which allowed us to keep a radially constant profile for the fixed blades, and a constant exit angle for the moving blades at each stage, thus simplifying machining. The turbine as determined above gives the expected performance and its optimum efficiency is over 88 per cent.

As stated above, the maximum temperature ahead of the turbine was to be 600°C. (1,112°F.), which corresponds to a working temperature for the first row of moving blades of 550°C. (1,022°F.). At this temperature and for an allowable blade root

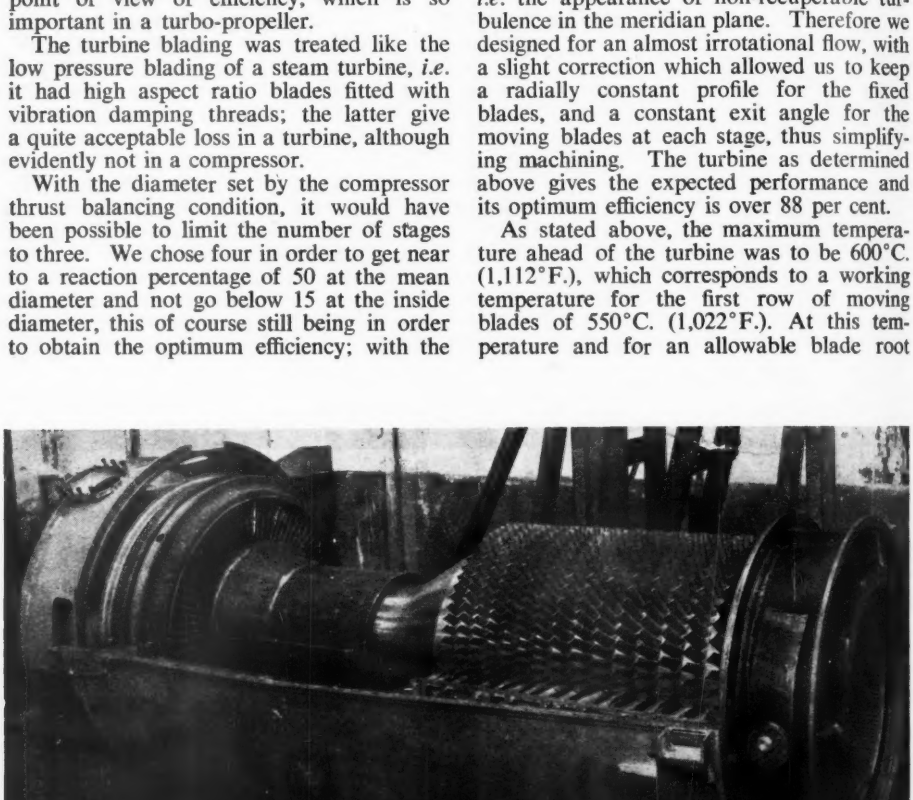


**Fig. 7.**

TGA-1 bis. Rotor mounted on lower casing.
Note from right to left the reduction gear position, the air entry, the reduction gear casing, the compressor, the shaft protecting shell, the first fixed row of the turbine.

stress of 8.25 to 10.15 tons/in.² from the first to the fourth moving row, there are nowadays many suitable materials. At the time (1941) this was not the case, and we chose the Jacob Holtzer 1480 steel, which at 550°C. (1,022°F.) has a creep limit of 12.7 tons/in.² according to the Veritas definition, *i.e.* a plastic strain increase of 1/100,000 per hour, measured between the 25th and 35th hours. This steel can be forged even in large sizes and is easily weldable, and was also chosen for the turbine discs and for the drum between the turbine and compressor. The compressor drum was in CMO7 chrome-molybdenum steel, which could be welded to the 1480 steel and had a higher elastic limit when cold (34.8 tons/in.²).

The fixed blades, which were more highly stressed than the moving ones, were designed in the ATVS grade of the Acieries d'Imphy, which had a Veritas creep limit of 19 tons/in.² at 600°C. (1,112°F.).

The most difficult problem to be solved for this project, as indeed for most aviation turbines, was that of combustion. To achieve a combustion chamber within an acceptable volume, we had to get a combustion rate 10 times higher than the maximum known at the time (forced boilers), and there was nothing to give us a clue as to the means of achieving this result. If present-day chambers are extremely simple, it seems that they have required considerable research work, and that their simplicity is paid for by a high pressure loss; for a turbo-propeller engine a relative pressure drop of three per cent. means nearly 10 per cent. increase in specific consumption.

If in the early stages of our design work our ignorance of the possibilities of atomisation chambers made us uncertain of achieving the required combustion with the form of turbo-engine envisaged, and consequently did not allow us to try in that direction, on the other hand some experience with the combustion of gaseous fuels, and a few rapid tests with vaporised petrol, made us certain of the possibility of obtaining the required combustion rate. Combustion of petrol vapour on grids or honeycombs can take place under good conditions, given a suitable choice of length of grid and of cell diameter, up to speeds of 19.7 to 26.3 ft./sec.

Allowing a speed of 19.7 ft./sec. for the mixture of primary air and vaporised fuel, which means about 20 per cent. of the total air flow, and 82 ft./sec. for the velocity of secondary air, one can easily verify that it is

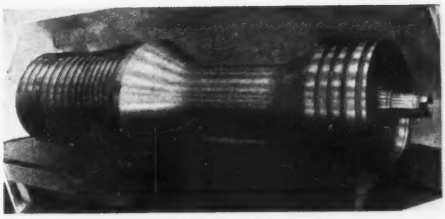


Fig. 8.
TGA-1 bis. Rotor without blading.

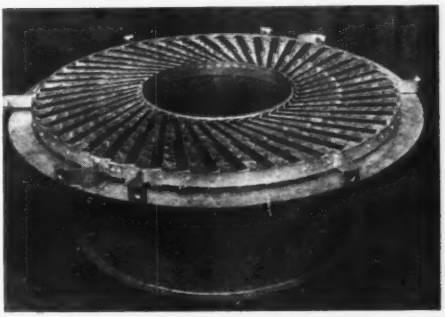


Fig. 9.
TGA-1 bis. Vaporisation combustion chamber assembled.

possible to get 1,300 h.p. per atmosphere per square foot of combustion chamber section. The blue flame anchors itself on the edge of each honeycomb cell and its cone length is very small; it depends on the cell diameter, and in our case with 0.2 in. diameter cells the length did not exceed 3.2 inches. At 1,300 h.p. per square foot per atmosphere and with a length of 3.2 inches it is theoretically possible to get 4,800 h.p. per ft.³, per atmosphere, which is a great deal more than is obtainable from present-day atomisation combustion chambers. Moreover, this is achieved with negligible pressure loss. Indeed the passage of the primary air through the grid takes place at such low speed that the pressure drop is negligible. The secondary air enters freely into the chamber, and if the velocity decrease at the compressor exit takes place in channels of the right shape, a great deal of the corresponding dynamic energy can even be recuperated. There remains only the intrinsic energy loss due to the irreversibility of the combustion, which results from the increase in gas velocity due to its sudden change in volume. In our case, this increase

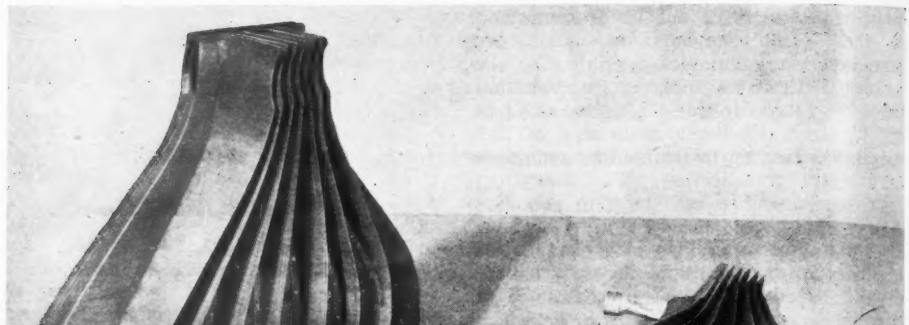


Fig. 10.
TGA-1 bis. Vaporisation burner.

in velocity was from an average value of 68.9 ft./sec. to 134.5 ft./sec., which means a loss of less than 0.2 per cent.

Finally, there was a third advantage expected, namely, that in this system combustion takes place with a non-radiating blue flame, and hence the burners and chamber walls are free from hot points. Indeed the burners and even the grids could be made in aluminium, so long as we could be certain that mishandling and untimely flow of liquid fuel on starting or stopping could be avoided.

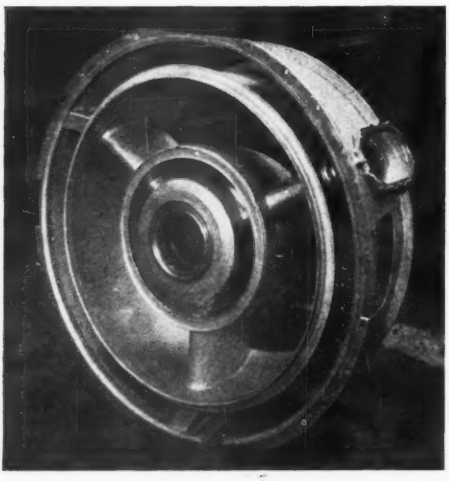


Fig. 11.
TGA-1 bis. Rear bearing.

All these theoretical advantages unfortunately were to be paid for dearly enough. First, one must ensure the mixing of hot gases and secondary air in the absence of that turbulence which is present in high pressure loss chambers. To this end we had given the burners, which were 48 in number, the shape of thin sectors, thus achieving thin layers of hot gases separated by as many layers of secondary air. Further, to avoid any accident to the fixed turbine blading in the case, for instance, of a burner having been fed with excess fuel, the burners were set obliquely to the radius. These excessive precautions may seem amusing, when one thinks of the huge temperature differences which can be stood by turbines with some atomisation chambers, but we were very keen on getting perfect homogeneity, both to ensure good mechanical behaviour of the blading and to get high turbine efficiency.

Although in principle combustion was to be completed at 3.2 inches from the burner

grid, in order to obtain perfect mixing and also by way of precaution, we had given to the chamber a total length of 19.7 inches from the burner grid. This was one of those pieces of luck for us, which—fortunately for engineers—sometimes come to compensate their ignorance or rashness; for in 1946, when the development of the vaporisation chamber was giving us some trouble and consequently we had rapidly brought out an atomisation chamber—incidentally meant for another engine— it allowed us to replace the former by the latter without altering the main components of the engine. This atomisation chamber indeed fits so well into the space intended for the vaporisation chamber that one would think that the engine had been laid out for the second solution.

In order to ensure correct distribution over the grid of the primary air—fuel mixture, we had given each burner of the vaporisation chamber a number of channels to give a gradual slowing down of the air. Similar channels ensured the slowing down and even distribution of the secondary air. It was the number of burners and of channels per burner which led to the first development difficulty of this chamber. It is difficult to ensure that each channel gets the correct proportion of fuel and primary air. The result is that some channels are too rich and some too poor to the extent of going out as soon as the speed departs from that for which the system has been adjusted.

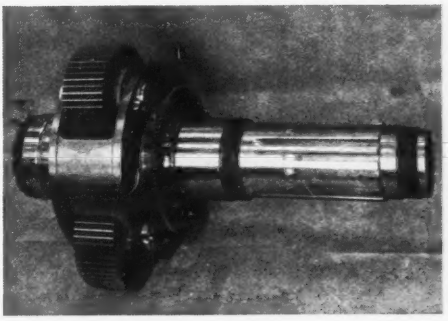


Fig. 12.
TGA-1 bis. Reduction gear.

Vaporisation of the fuel was carried out in a coil surrounding the combustion chamber. The vaporised fuel was then fed to each burner by collectors, which unfortunately were heavy and cumbersome. To avoid partial condensation of the fuel vapour

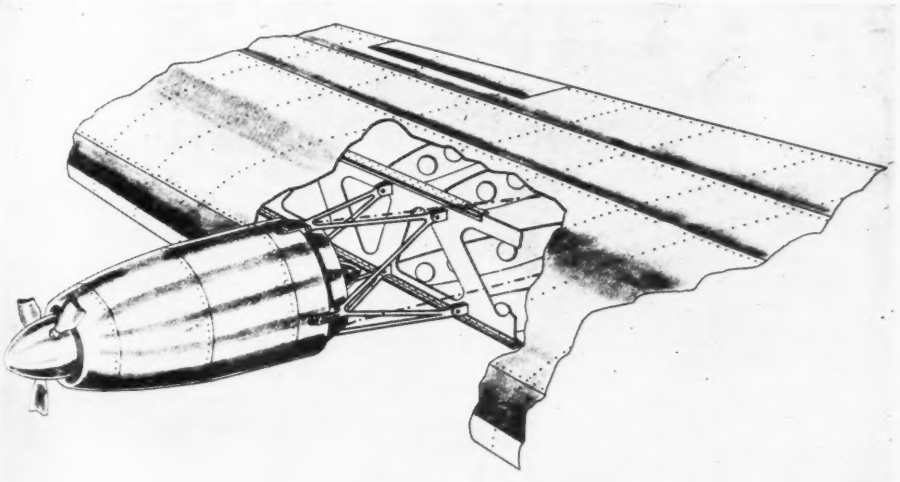


Fig. 13.
TGA-1 bis. Wing mounting.
Note the principle of the mounting of the engine on the wing spar. Gases go through the wing spar by a triangular duct. The engine axis is at the same height as the wing spar axis, which gives the lowest overall drag.

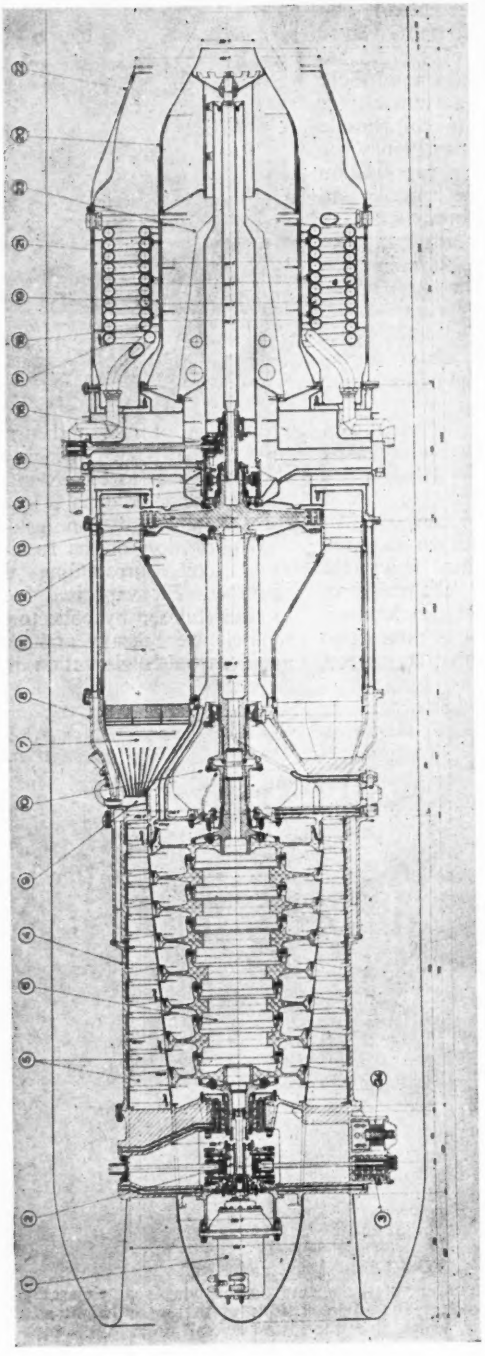


Fig. 14.

TGAR-1008. General plan of vaporisation type.
Note from left to right the 8-stage compressor, the vaporisation chamber, the turbine, the vaporisation coil, the adjustable jet duct.

on the burner walls, which remain at the temperature of the compressor exit air, we achieved an air-fuel vapour mixture in the coil in such proportions that the dew point of the mixture should be higher than the temperature of those walls. In our case it was sufficient to provide a weight of air equal to the weight of petrol, and this air was supplied by a little air booster, the inlet of which was connected to the outlet of the engine's compressor.

We believe that our vaporisation combustion system is substantially different from those tried in Britain and which are giving such good results at Armstrong Siddeley's. Firstly the speed of the primary air-vaporised fuel mixture is reduced to a value such that the anchoring of the flame is maintained in the absence of deliberately provoked large scale turbulence. Similarly the hot gas secondary air mixture is obtained solely by the working of the burners. Finally, vaporisation is carried out in a coil of large area surrounded by gases at a relatively moderate temperature, and hence carbon deposition is not to be feared.

Although since 1946 we have had a satisfactory atomisation chamber, we have equipped one of our turbo-propeller prototypes with a vaporisation chamber. Tests confirmed our fears; the bad distribution of the fuel in the various burners and in the various channels of the same burner caused both a high proportion of unburned fuel and a lack of flexibility in the chamber. Having another and simpler solution at our disposal, we then provisionally abandoned the vaporisation chamber, for turbo-propeller engines at least.

Our engine turns at 6,350 r.p.m. and the propeller at 1,100 r.p.m. We designed a single-stage epicyclic reduction gear with three satellites, which transmits a maximum power of 2,560 h.p., weighs 529 lb., has a maximum diameter of 19.7 inches and a length of 15.7 inches. The only special feature to which we shall draw attention is the elastic mounting of the bearings of the primary pinion in the planet cage, the pinion —which is driven by a flexible shaft—thus being free to take up its optimum position. This gear has as yet an insufficient number of hours to its credit to enable us to judge its endurance. Its efficiency is of the order of 98 per cent., as evaluated by the amount of heat taken away by the oil and air.

We have already noted that one of the virtues on which we counted for this engine was low frontal area. To this end we wanted to avoid the presence of any auxiliary or structural component immediately around the unit. The compressor and turbine cylinders, the only function of which was to carry the fixed blades, were themselves mounted within a sheet metal shell, which ensured both the rigidity and pressure-tightness of the machine. This shell had on its rear face four very robust lugs which were to link it to the aircraft wing spar through a system of connecting rods. The engine axis was about at mid-height of the wing spar, which, in the aeroplane which had been designed to be fitted with this engine, was arranged to allow the exhaust gases to escape through a triangular opening. Thus one could really achieve the lowest possible drag, the engine cowling being closely fitted and not exceeding its own maximum diameter, namely 45.3 inches, a dimension which was nearly equal to the wing thickness. The auxiliaries were gathered into a compact group and mounted at the side of the engine in the wing leading edge, and driven by shafting through bevel gears.

If we are giving these details concerning the installation of this turbo-propeller unit in the aircraft, which events prevented from being completed and if sound judgment is to be passed upon it, the general idea which presided at the design of the engine and gave it its form must be understood. Because of the improvement of the cycle as compared with that which we adopted in 1941, modern turbo-propeller engines of the same power have main elements—compressor and turbine —of much smaller diameter. Under these conditions it is logical that mountings, auxiliaries and cowlings, should have assumed relatively more importance. But it seems that, at least for some aircraft such as fast twin-engined types, the search for the lowest possible drag of the turbo-propeller nacelle has, indeed, the great importance which we thought it had:

We have mentioned that during the Occupation we were unaware of the very existence of British and German turbo-reaction engines. But from January 1944 the B.B.C. began talking about these new aeroplanes without propellers, and despite the complete lack of technical data we suspected that the power units must be turbo-reaction plants derived from the work of Air Commodore Whittle, of whose first

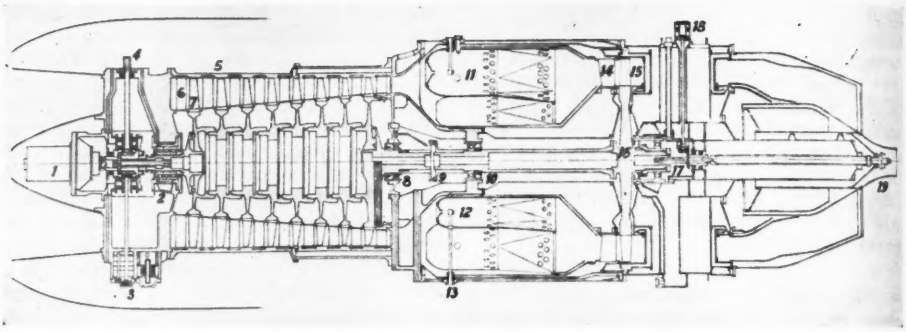


Fig. 15.

TGAR-1008. Diagrammatic section of atomisation type.

1. Starter motor.
2. Forward bearing.
3. Oil pump.
4. Take over point for movement.
5. Cylinder of compressor.
6. Fixed blades of compressor.
7. Moving blades of compressor.
8. Bearing.
9. Coupling.
10. Turbine shaft bearing.
11. Large combustion chamber.
12. Small combustion chamber.
13. Injector.
14. Fixed blades of turbine.
15. Moving blades of turbine.
16. Turbine disc.
17. Rear bearing.
18. Cone control.
19. Regulating cone.

patents we were aware. From the German side we had had whispers of the existence of reaction aeroplanes through people whose job it was to have information, but we had no clue as to the kind of engine used. It was immediately after the Liberation, at the end of August 1944, that partially destroyed Jumo 004 jet engines were found in a machine-gunned and burnt-out German lorry near Orleans. We never found out exactly what these engines were doing in France.

The S.N.C.A.S.E.,* with whom we had dealings, asked us to design a high power jet engine for a fighter bomber which they were designing. After several exchanges of views, we agreed upon a unit with a static normal thrust of 4,190 lb. and a diameter of about 39 inches.

A quick study showed us the possibility of achieving such a unit at a weight of 2,645 lb. with a minimum consumption of 1.18 lb./lb.-hr. Such characteristics seemed to us to compare quite well with those of the Jumo 004. Here again we were lucky in not knowing the characteristics of the Rolls-Royce Nene which was in being at that time, for otherwise we should have had the wind taken out of our sails, and should perhaps never have proceeded with our turbo-jet engine, which we are glad to have now, for one must begin sometime and furthermore, there is scope for improving substantially on the initially determined performance.

For this unit, which was designated TGAR 1008, as for the turbo-propeller engine of 1941, we had made some sacrifice of performance in favour of speed of manufacture and reliability. Above all it was a question of rapidly getting out a jet engine of French construction having a high thrust. In the autumn of 1945 a schedule was made out according to which this engine was to be on test in December 1946; our optimism at the time, which can be understood after the years we had gone through, made us forget that in our country everything had to be started up again from scratch, and that an aircraft prototype would often have to mark time, particularly because of the material supply position, in view of vital priorities.

Having already started on the path of the turbo-propeller engine with axial compressor, we naturally continued in the same direction for the turbo-reactor. But from 1939 to 1945 our knowledge of blading had not increased, for reasons which are obvious. Thus we made a close study of the compressor of the Jumo which, with moving blades similar to ours, had an actual temperature rise per stage of 16.5°C. (29.7°F.) with an excellent efficiency. Indeed, the efficiency of the Jumo

* Société Nationale de Constructions Aeronautiques de Sud-Est.

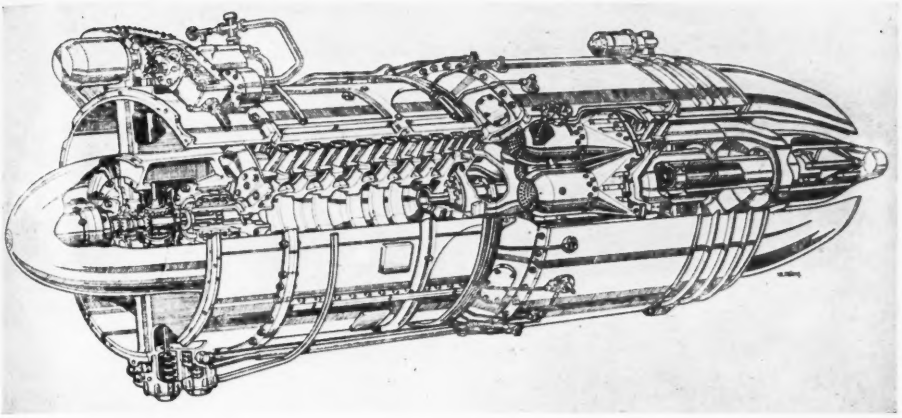


Fig. 16.
TGAR-1008. Perspective view.
Note from left to right the starting motor, the front bearing, and, below, the auxiliaries gear driving the fuel pump.

is 83 to 84 per cent at its maximum speed of 8,700 r.p.m. (and even 88 per cent. at 7,000 r.p.m.), and not 78 to 79 per cent. as has been published. This is because the figure of 79 per cent. was measured on a machine fitted with an entry diffuser, which is determined by conditions of optimum performance at speed, and which is the cause of high losses in the static condition. In fitting a Jumo 004 with a simple suction hood, its static thrust is actually increased by 6 per cent. The reaction percentage of this compressor is 100, and the high specific work per stage, with low deflection moving grids, is due to the high relative velocities allowed. At the tips of the first moving row the Mach number reaches unity in the static condition. The high efficiency is due to the low thickness of the moving blades, and confirms once more that moving blade systems behave better in an actual compressor than in a wind tunnel, particularly at high Mach numbers.

Basing our plans on this valuable experience, we then designed for our engine an eight-stage compressor with 100 per cent. reaction giving an actual temperature rise of 20°C. (36°F.) per stage with a compression ratio of 3.7. Besides the above considerations this apparent change in our policy was due to the fact that, for a turbo-jet unit, high compressor efficiency is of less fundamental importance than for a turbo-propeller engine, while minimum weight is perhaps more important. Such at least was our view in 1945, and it has evolved since then, in the face of the possibilities of present-day axial compressors and the development of turbo-reaction power plants.

In the case of our turbo-jet engine, the compressor once more is broadly giving the expected performance. But like the turbo-propeller unit it has not been bench tested, for as yet we have no installation capable of driving compressors of such powers at high speeds. Thus we must make provision for determining the characteristics of these compressors on the complete machine; perhaps this is an entrancing pastime, but engineers who have produced turbo-jet or propeller engines with compressors which are well known in all their aspects will understand all that our method of proceeding involves in the way of limitations, losses, and repressed impatience.

Many reasons prevented us from keeping the two-bearing layout used for the propeller unit, while the high weight of the turbine made us incline to bring the latter's second bearing to the exhaust side, out of caution. This high weight of the turbine, which yet had but one stage, was again the result of our desire to ease rapid manufacture; for instance, the blade fixing was of the multiple lug type and there is no doubt that the most

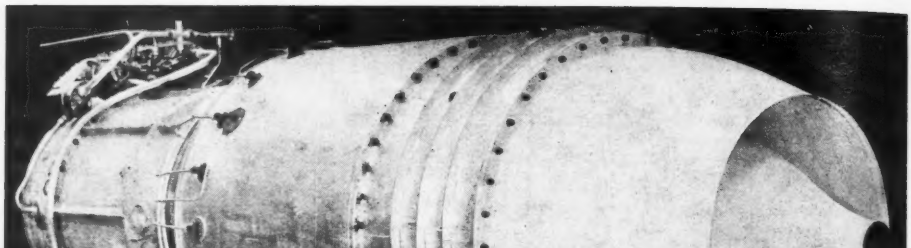


Fig. 17.
TGAR-1008. View from the rear.
Turbo-jet unit of 4,200 lb. static thrust at cruising revs., diameter 39 in.

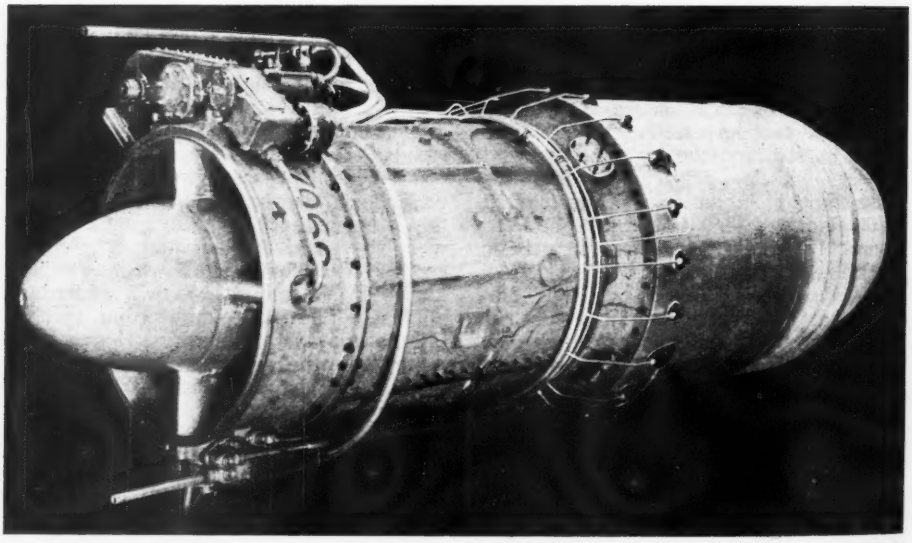


Fig. 18.
TGAR-1008. View from the front.

efficient type is the fir tree, which, however, requires more complex tooling. The rear turbine bearing is situated in a stream of very hot gas, but thanks to careful ventilation of the double walled arms and of the bearing body it behaves perfectly, and the roller bearing keeps to a very moderate temperature.

The fixed blades of the turbine distributor embody a special cooling arrangement based on the ideas of M. Darrieus, Chief Engineer to the Cie Eléctro-Mécanique. These ideas relate to the protection of the blades by means of a boundary layer of cold air surrounding them and we had made systematic tests on this system well before the war. It had allowed us to work a turbine at 900°C. (1,650°F.) without exceeding a blade temperature of 500°C. (932°F.), by supplying a flow of protecting cold air, which for each row of blades was a very small percentage of the total flow through the turbine.

For the turbo-reaction unit we did not intend to apply this system to the moving blades, but only to the fixed ones. As, however, we did not expect a temperature higher than 800°C. (1,470°F.) after combustion, the full protection of the fixed blades

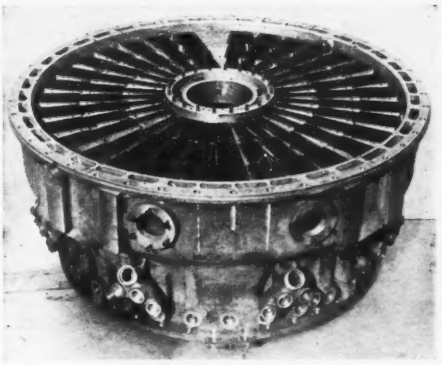


Fig. 19.
TGAR-1008. Arrangement of vaporisation burners.

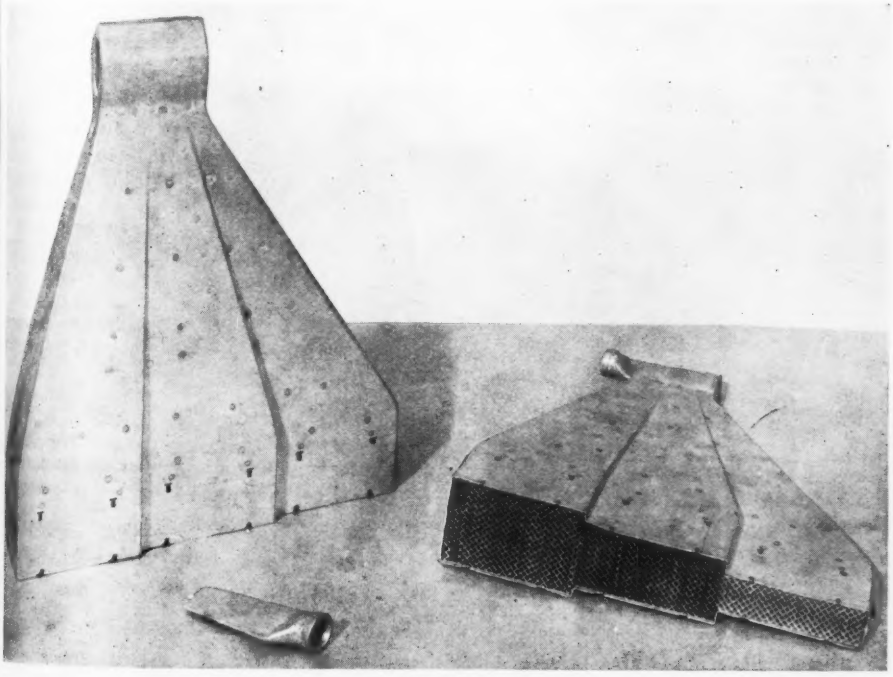


Fig. 20.
TGAR-1008. Vaporisation burner.

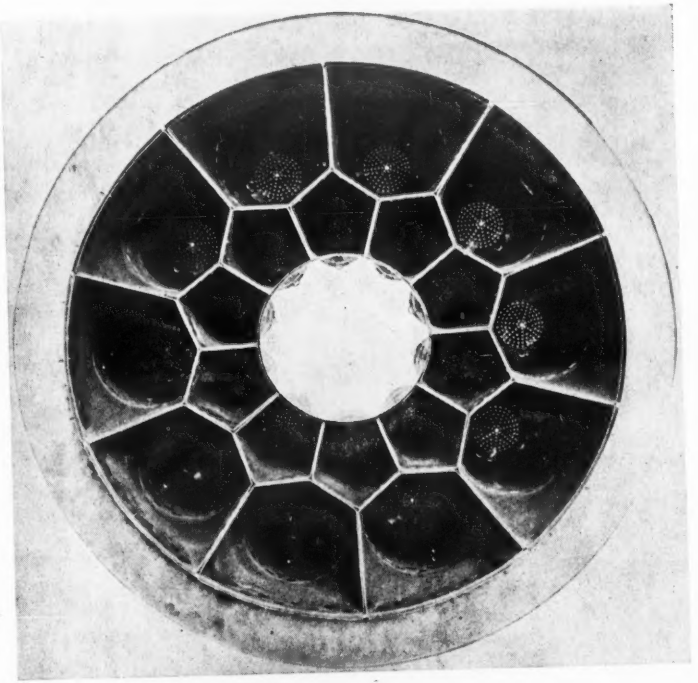


Fig. 22.

TGAR-1008. Atomisation chamber seen from the rear.

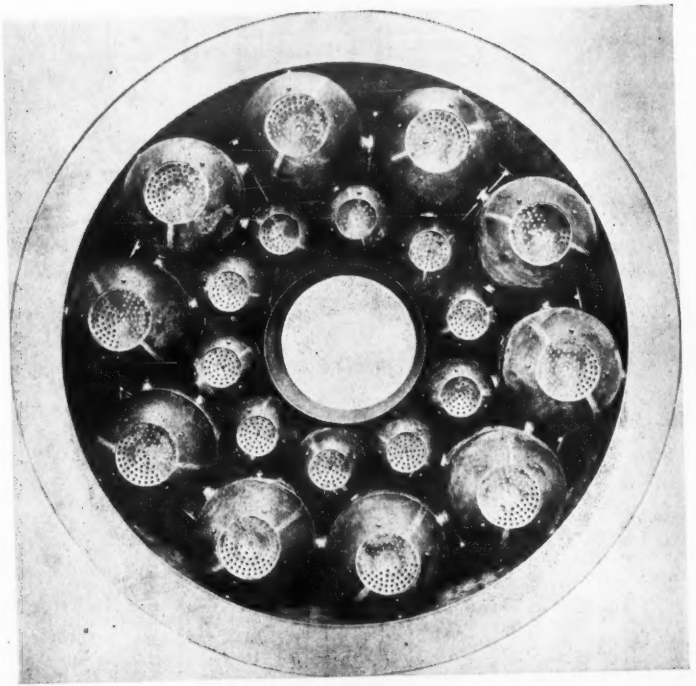


Fig. 21.

TGAR-1008. Atomisation chamber seen from the front.

by the boundary layer method would have been excessive; thus we applied it only to the under-surface of the blades, which greatly simplifies construction. Furthermore, still for the sake of simplicity, we went counter to the principle of this system, which requires that the boundary layer be fed through a continuous slot located as near as possible to the leading edge, and merely provided a number of orifices in line. The protecting air enters the hollow blade at one of its ends, flows inside to the tip and cools the upper surface wall, then round and back by the under-surface, feeding the orifices. This protecting air is taken from the compressor outlet. The result seems satisfactory, and the distributor blades work at a temperature 250°C. (450°F.) lower than the gases after combustion, with a protecting air flow of about one per cent. of the total flow.

The turbine fixed and moving blades are in Jacob Holtzer's Sirius HT. This is an austenitic steel with a creep of 0.5 per cent. in 300 hours at a stress of 9.52 tons/in.$^2$ at 700°C. (1,292°F.) and 15.2 tons/in.$^2$ at 600°C. (1,112°F.). The fixed blades are made from 1.5 mm. sheet and the moving blades are machined from stampings. The turbine disc is in Jacob Holtzer 1480 steel, the characteristics of which we gave in connection with the turbo-propeller engine.

The compressor is completely in light alloy. The moving blades were stamped to finished size by the Compagnie Générale du Duralumin in their Boisthorel works.

Combustion also set a very difficult problem for the turbo-reaction unit. It was in 1945, and the only example of atomisation combustion chamber we had was that of the Jumo 004, which was hardly encouraging (duration 25 hours, unburnt proportion 12 per cent.). At first we provided a vaporisation combustion chamber on the same principle as that of the turbo-propeller unit, but the problem was much more difficult. Indeed, while in the propeller engine the air flow was 61.7 lb./sec., in the jet unit it went up to 97 lb./sec. at the same pressure, while the frontal area was of the same order, namely that corresponding to 39 in. diameter. Furthermore we had to deal with a higher temperature rise. Thus the velocity of the primary air-fuel mixture had to be raised to 29.5 ft./sec. and that of the secondary air to 279 ft./sec. Under these conditions the combustion chamber could be fitted within the required space, but the sensitivity of

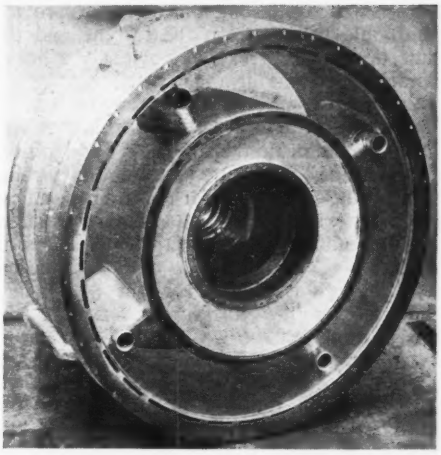


Fig. 23.
TGAR-1008. Rear bearing—vaporisation type.

combustion to inequalities of distribution became even worse.

Fuel vaporisation could not be done so simply as in the propeller unit in a coil surrounding the combustion chamber. The heat exchange surface obtainable by this

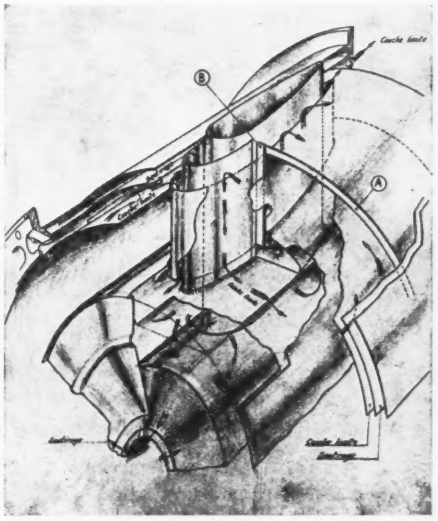



Fig. 24.
TGAR-1008. Diagrammatic section of rear bearing.

means was insufficient, and we had to provide a double coil between the turbine and the injection duct. This was obviously a heavy and cumbersome arrangement.

As for the turbo-propeller engine, one of the turbo-jet units was fitted with a vaporisation combustion chamber. For ignition, injectors had been fitted behind the turbine to heat the coils, while for the turbo-propeller engine we started up—at least provisionally—with butane gas, until the coil was hot. Ignition of the turbo-jet with its injector system was achieved in about 30 seconds but, as for the turbo-propeller unit, the unburnt percentage was high.

In view of the drawbacks of the vaporisation chamber, especially in the case of the turbo-jet, and the uncertainty of the result, during the course of the design we undertook the development of an atomisation chamber. As the engine was already settled in its main features and purchase of the main components was under way, the first condition which we laid down for this chamber was that it should be annular, and that it should make the best use of the existing space. To this end, the chamber was worked out as a

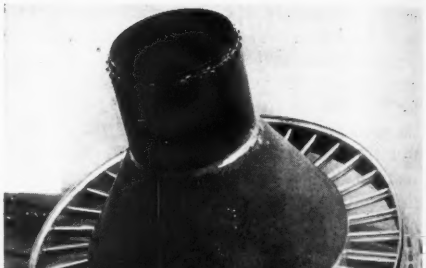


Fig. 25.

TGAR-1008. Turbine distribution.

Note on the undersurface of the blades (bottom left of picture) the line of holes through which the blade protection air escapes.

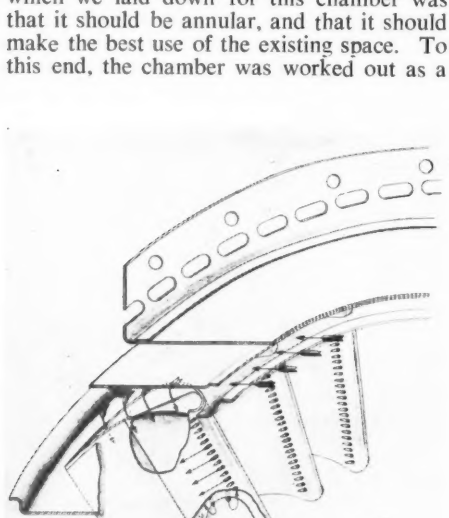


Fig. 26.

TGAR-1008. Diagrammatic section of turbine distributor.

Arrows indicate the path of the protecting air flow, which is taken from the compressor exit.

number of flame tubes of different diameters disposed axially on two concentric pitch circles. These tubes were placed in the annular chamber, but while their section was circular at the upstream end, they were progressively deformed towards the downstream end, in such a manner that at their exit they again formed an annular section between them. In short, the chamber is annular if one takes the whole of the flow—primary and secondary—but combustion takes place in cylindrical flame tubes.

As we have said, the reason for the two sets of tubes was to make the best use of the available space between the compressor and the turbine. Because of the position of the rear turbine bearing, the diameter of the shaft protecting tube was small, and this accounts for the disadvantage of the series of small diameter flame tubes. This arrangement however has several advantages. For one thing, it can be used to limit the temperature at the root of the moving blades, by raising that of the outer tubes in relation to that of the inner ones, thus reducing the thermal stresses in the disc and the temperature of the blades at their point of highest stress.

In our case the smaller tubes having to take 27 per cent. of the total flow, a tempera-

ture difference of 200°C. (360°F.) between the two zones would mean an average temperature only 50°C. (90°F.) lower than the maximum temperature. With most types of combustion chambers designers have tried to reduce slightly the temperature at the roots of the moving blades as compared with the average temperature. With our arrangement this difference can be positively controlled and if necessary can even be varied with engine r.p.m., if the injectors for the larger and smaller flame tubes are fed with independent values of fuel pressure.

We think that the arrangement with two banks of concentric tubes will improve functioning at low revolutions at high altitude. For if, at high altitude, when the thrust is to be reduced to as low a value as possible, the fuel supply to the larger tubes is cut off and the supply to the smaller tubes adjusted to a pressure just sufficient to get a stable flame with minimum richness, the machine then working almost in auto-rotation, it should be possible both to avoid the flame going out, and to reduce thrust to a negligible value, keeping also undisturbed the circumferential distribution of temperatures. Furthermore the pilot could at any time be sure of re-igniting all the tubes, as we have been doing on bench test. So far this is only a hope, as we have not yet flown this engine. Complicated control gear would also be required, and although this is not yet in existence it offers no difficulties in principle.

This chamber with separate flame tubes is now allowing us to do away with the rear turbine bearing and to replace it with a front bearing, which is linked to the outer cylinder by arms crossing the chamber in between the flame tubes, through the secondary air flow.

Our turbo reaction engine is regulated by r.p.m. The Société Bonzavia undertook the design of the regulator, which is to be based on that of the Jumo. The regulator, at first set on the test bench, then fitted to the engine, immediately fulfilled its functions, without requiring any adjustment or development. Fuel supply is carried out by high pressure gear pumps which, together with all controls and auxiliary drive gear, were manufactured by the Société Air-Equipment.

This summary of our work, of which I have tried to show the framework—so different from what it has been elsewhere—will, I hope, have been of interest to you because it has described the genesis of aviation turbines from foundations and technical processes quite different from those to which you are accustomed. But perhaps it would be unfair to draw a parallel between the results achieved on one side and the other, unless a judicious handicap were determined before general conclusions were drawn.

I should like to thank all those who, during the Occupation, at a time when everyday reality was tragic enough, allowed our little team of technicians to devote themselves to an enthralling enterprise turned towards the future; that is something the value of which is inestimable.

## DISCUSSION

**The President** (Dr. H. Roxbee Cox, *Fellow*): A number of members of the Society had visited France in May 1948 for the first Louis Bleriot Lecture and some had had the good fortune to visit the works of the Cie Eléctro-Mécanique, where they had seen running a turbo-propeller engine and a jet-propulsion engine. They had realised that those two machines were the result of a remarkable lone effort made largely in the most unfavourable conditions possible—during the German Occupation of France. Not only had they felt that that achievement was remarkable, but the engines had features of considerable intrinsic interest.

As the designer of the engines, M. Destival was asked to prepare a lecture to be presented to the Society. Because he had felt that his command of the English language was not quite equal to the occasion it was arranged that M. Bidard, the Chief Engineer of the Company, should come to England with him to read the paper. Unfortunately, M. Destival had been ill for the past month, but it was pleasing to hear from M. Bidard that he was really getting better, and they all wished him a speedy recovery.

He congratulated M. Bidard on his presentation of the paper.

He had become more impressed than ever by the excellence of that very lone effort which the paper described. He was impressed first of all by the similarities between the French design and the British; but he was even more impressed by the differences, some of which showed an ingenuity and skill which they would all admire and from which they could learn. The geometry of the combustion chambers in the jet engine, and the way in which the protecting cooling air was introduced, were of great interest.

**G. S. Moult** (Chief Engineer, The de Havilland Engine Co. Ltd., *Fellow*): They were grateful to the author for his excellent presentation of a noteworthy development, carried out under very great difficulties. They were grateful also to M. Bidard for his excellent delivery; but they owed him far more than that, for he had had a great deal to do with the developments described and had been responsible for a major portion of the work.

Some months ago he had had the opportunity of visiting the Cie Eélctro-Mécanique in Paris and of examining in some detail the activities described in the paper. It would be agreed, bearing in mind the circumstances of the Occupation and the difficult post-war years, that the work described constituted a most worthy achievement. As the President had remarked, the engines incorporated many interesting features, and they could all benefit from a close study of those features.

It was noteworthy that the French engineers did not accept the simplest solutions, but preferred to achieve an efficient and compact layout. The compression efficiency of 85 per cent., which presumably was the overall isentropic efficiency, was very satisfactory, and a tribute to good aerodynamic design. While he was in Paris he had seen some of the research activities which constituted the background of that aerodynamic achievement, and the methods employed were both original and thorough.

At the same time, he would like to hear the views of M. Destival and M. Bidard with regard to the specific fuel consumption of 1.18 lb./lb.-hr. With a compression ratio of 3.7, a maximum temperature of 800°C., and an ideal air intake, one would have expected a figure of about 1.04 lb./lb.-hr. If good individual component efficiencies had in fact been achieved, the inference must be that the matching of the compressor and the turbine was still not the optimum required to bring their efficiencies to a peak simultaneously. Many constructors in Great Britain and elsewhere had experienced the same difficulty with the sharp characteristics of the axial type compressors. Better consumption figures had in fact been obtained with centrifugal machines having compressors of admittedly lower efficiency, but with more obliging characteristics.

Had it been necessary to instal a blow-off valve in the compressor to take care of starting and accelerating, and what rate of acceleration had been achieved?

The cooled static blade was a most interesting development, and should permit the use of either a lower grade material in the future, or a higher operating temperature. Blades of that type might be of greater use in propeller-turbines, which could employ with efficiency higher temperatures than could the pure jet engine; the latter, thermodynamically speaking, should err on the side of modest operating temperature.

He imagined from the description of the welded drum construction that it involved welding a ferritic to an austenitic steel; had any cracking developed at the welds arising from the different coefficients of expansion?

It would be helpful, in assessing the excellent work described, if some indication could be given of the total running time achieved with the units and the degree of reliability achieved on the test bed at the designed duty.

**A. G. Smith** (National Gas Turbine Establishment): In the stator cooling system, could M. Bidard indicate what degree of loss in aerodynamic performance was entailed in the method of cooling air injection?

Had trouble been experienced because of uneven cooling, with consequent stressing and buckling, with that method?

**N. J. Hancock** (*Assoc. Fellow*): He was delighted by the charming frankness with which the author had given details of the "shots in the dark" that were made and of the "spots of luck" that were experienced, which he felt contrasted somewhat with the reticence sometimes found in Great Britain among their own designers.

He would like to hear more about the difficulties that were experienced in obtaining suitable steels for the high-temperature highly-stressed parts of the engines. In this country they had had quite a lot of trouble in that connection.

**I. M. Davidson** (National Gas Turbine Establishment, *Student, R.Ae.S.*): He was

interested particularly in the details given of the compressor of the first engine; the only other information he had come across concerning the very high Mach numbers was contained in a paper by Professor Weise, in Germany, where some clear photographs were shown of the flow around the blades at 0.7 Mach number. There, because of local supersonic over-expansion, the cascade was not operating properly. Could M. Bidard give information concerning the air angles in the first stage of his 8-stage compressor, and the performance achieved?

**R. H. Schlotel** (*Fellow*): Mr. Moult had asked for figures relating to the performance of the engines, but it seemed from the paper that neither of the engines had actually flown. Did they plan to test them in flight?

A point which interested him particularly was that the horse power of the propeller-turbine engine was somewhat more than they should reckon to put through a single shaft propeller. He would like to hear more about the size of propeller envisaged.

The many original features which the designers had put into their engines were extremely interesting; he wondered whether, and to what extent, the excellent measure of collaboration between the various firms in Great Britain tended to make their designers follow each other, rather than to introduce new ideas into their own designs.

**F. C. Sheffield** (*Flight*): He would like information about the turbine of the TGA unit. It had been stated that the blades were fitted with "vibration damping threads which gave quite an acceptable loss in a turbine, although not in a compressor." Would the author give the value of this loss?

Referring to the compressor of the TGAR unit, was it to be understood that all the blades and the discs were of light alloy?

He was not clear in his mind concerning the configuration of the cooled stator blades of the TGAR turbine. It would be of interest to know the material and the gauge of the sheet metal internal baffle, the temperature of the entering air and the velocity through the blade.

Because of the order of presentation, it might be inferred that the picture of the complete TGAR unit showed the vaporising combustion chamber, but he gathered it was the atomising chamber. Would M. Bidard confirm or correct this impression?

**V. N. Butler** (Omes Ltd., *Associate*): The wonderful effort that had been made in France under very difficult conditions was amazing and they must have worked with cool heads as well as cool blades.

Had M. Destival and M. Bidard considered the use of any of the lower category fuels in the engines described, and could they indicate the average life of the combustion chambers?

**W. E. P. Johnson** (Power Jets (R. & D.) Ltd., *Assoc. Fellow*): Would the author revert to vaporised combustion if satisfactory distribution could be achieved?

He wondered whether any mechanical troubles had been experienced because of the rearward location of the turbine bearing, *e.g.* troubles arising from distortion or mis-alignment, particularly in cooling off after a run?

**W. H. Lindsey** (Armstrong Siddeley Motors Ltd., *Assoc. Fellow*), *contributed*:

1. He would be interested to know how nearly the performance figures for the TGA were approached on test? Far from being high, the target figure of .78 lb./h.p./hr. for the sea level static condition was an exceedingly good figure if based on actual shaft power output.

2. The extensive use of 100 per cent. reaction compressor blading was very interesting. They had thought that the great advantage of this type of blading was its characteristic of zero pressure rise in the stators enabling very simple stator sealing arrangements to be used, but they would not have expected to obtain the high efficiencies quoted.

3. With regard to blade vibration characteristics, their engines must operate successfully at all speeds from about 70 per cent. full speed upwards. They tried to keep the fundamental frequency of any blade higher than any forced vibration which could occur up to the full speed of the engine.

4. He was naturally interested in the experience obtained by M. Destival with vaporising combustion and would like to make the following points:

(*a*) They thought that 20 ft./sec. was about the limit of flame velocity for primary combustion, which agreed fairly well with the figures of 19.7 to 26.3 ft./sec. quoted in the paper.

(*b*) He was not quite clear whether the figure quoted for combustion intensity of 4,810 h.p. per cu. ft. was meant to be "per cu. ft. per atmosphere," but assuming that was so it agreed well with the combustion intensity in the Mamba chamber primary zone which was $7.23 \times 10^6$ c.h.u./cu. ft./hr./atmosphere, which was equivalent to 5,100 h.p./cu. ft./atmosphere.

(*c*) They had examined a similar scheme at various times over a period of years, but had not put it into practice because of the following disadvantages:

1. Difficulty of piping vapour from vaporiser to inlet grid, without loss of heat if the pipes passed outside the flame tube, or over-heating if inside the flame tube.
2. Problem of obtaining even distribution.
3. Possibility of a "strike back" of the flame to the interior of the duct in view of the low velocities used.
4. Reduced stability range due to lack of recirculation.
5. Problem of mixing seven times the weight of comparatively cold air to the very rich 1:1 mixture in the primary spaces which was required to complete combustion without slowing the reaction down unduly or even chilling the flame to an extent to prevent complete combustion.

He would like to congratulate M. Destival on an extremely interesting paper and to say how refreshing it was to see the problem of the provision of aircraft gas turbine engines approached from a different angle.

## M. DESTIVAL'S and M. BIDARD'S REPLY

**Mr. Moult:** The figures quoted were actually isentropic efficiencies valid for the whole compressor, and not stage efficiencies.

The consumption of 1.18 lb./lb. hour, with a compression ratio of 3.7 and a post-combustion temperature of 800°C., instead of 1.04 as calculated by Mr. Moult, was accounted for as follows:

1. For a compression ratio of 3.7 the compressor efficiency was only 82 per cent., at least with the present adjustment of the machine, and not 85 per cent. as Mr. Moult seemed to have taken, the latter figure being that which they quoted for the turbo-propeller engine.

2. This compressor efficiency was the isentropic efficiency as measured by the air temperature rise. The true efficiency used in cycle calculations must be reduced by the loss at the balancing piston, the air take-off at the fourth row (used for cooling the rear bearing), and the air take-off used for the protection of the turbine ducting.

3. Actually the turbine was not accurately matched as the compression ratio provided for at the design stage was only 3.3. In the design of the compressor, provision was made for various margins, which turned out to be unnecessary, and which explained the excess of compression work.

Consumption could certainly be appreciably reduced with turbine blading accurately matched to the present cycle.

The compressor had no provision against pumping. The accelerations of the machine were very satisfactory, and in particular much better than those of German reaction engines. Passing from the speed corresponding to 440 lb. thrust to that corresponding to 4,400 lb. could be easily done in 7 to 8 seconds. The adjustment was a compromise between that giving the best acceleration and that corresponding to the best matching of the compressor at full speed; this compromise seemed inevitable with an axial compressor.

In the TGA-1 bis turbo-propeller engine there was actually a welded joint between the ferritic steel (low carbon chrome-molybdenum) of the compressor drum and the austenitic steel (Jacob Holtzer 1480) which formed the rest of the shaft. This joint was specially developed in the laboratory, and gave no trouble on the engine; in particular there had not been any cracks. In any event, the technique used in the welding of these drums was rather complicated, and required elaborate tooling.

So far the total working time of all the reaction engines tested only amounted to a few dozen hours, and it was too early to draw conclusions on their endurance.

**Mr. Smith:** The method of duct cooling and protection certainly entailed aerodynamic losses, but in the present case, with the very small amount of protecting air used (one per cent. of the total flow), the losses were extremely small and hardly measurable.

There had been no trouble with eventual unevenness in protection, but they would

stress that they had not worked at post-combustion gas temperatures higher than 850°C.

**Mr. Hancock:** As stated in the lecture, the heat resisting steels used in the engines were the Acieries d'Imphy A.T.V.S. and the Jacob Holtzer 1480 and Sirius H.T. The first two were pre-war materials and fully developed. The Jacob Holtzer Sirius H.T. also behaved well, and they had no difficulty in forging, machining, and behaviour in service.

The combustion chambers were in Acieries d'Imphy ERA HR2 sheet steel, which was also a material which had been developed for a long time, and the application and working characteristics of which were well known.

**Mr. Davidson:** They had mentioned the Mach number values of 0.9 at the tip of the first moving row of the turbo-propeller engines and 1.0 at the tip of the first moving row of the Jumo. In both cases the grids had a fairly high pitch at this point ($s/c = 1.6$ for the TGA-1 bis and 1.77 for the Jumo), very thin profiles, and were set at 45° for the TGA-1 bis and 32° for the Jumo. From this it was possible to deduce deflection angles, which were very low. The mean Mach number of these rows was therefore lower than the above figures, and for the whole compressor lower still. Moreover, the Mach number reached high values only on the moving blades, for which the boundary layer flow was favourable to high Mach number conditions. For a compressor with a high reaction percentage, fixed bladings were working at very low Mach numbers. It was probably for these reasons that the efficiencies obtained with the Jumo compressor and with theirs were satisfactory, in spite of the high value of Mach number at the entry.

Actually, the efficiency of the turbo-reaction engine compressor (8 stages with 100 per cent. reaction) kept above 87 per cent. up to a compression ratio of 3.3, and then decreased, falling to 82-83 per cent. for a compression ratio of 3.7.

**Mr. Schlotel:** Neither the turbo-propeller nor the turbo-reaction engine had actually flown so far. A flying test bench was being prepared, which would take either engine. This test bench was a four-engined machine which had been fitted with a nacelle above the fuselage, capable of taking either engine.

The airscrew intended for the turbo-propeller engine was an orthodox three-blader of 13.9 ft. diameter, turning at 1,100 r.p.m. It had been designed by the Société Ratier. No tests with propeller had been done so far.

**Mr. Sheffield:** The losses caused in a turbine by vibration damping threads varied with the conditions under which those threads were used, but in any event they were very low, as proved by the efficiency obtained with the turbo-propeller turbine, namely .88 per cent.

The turbo-reaction engine compressor was actually entirely made of light alloy.

The sheet forming the internal baffles of the fixed turbine blades of the TGAR was in ordinary steel and of 0.028 inch thickness. The temperature of the air entering the blade was 175°C.

The complete TGAR engine shown in the slides was an atomisation type.

**Mr. Butler:** The vaporisation chambers were tested with ordinary automobile petrol. Atomisation chambers worked with kerosene of the same specification as that used in England for ignition as well as for normal running.

In view of the short period for which the prototypes had been running, they could not yet give any indication of the average life of combustion chambers.

**Mr. Johnson:** It was difficult to say whether or not they would resume the development of vaporisation combustion. Its theoretical advantages were purchased at the cost of such complications that it was to be feared that the atomisation chamber (which also would improve considerably) would always keep the lead, at least for aircraft purposes.

The bearing at the rear of the turbine, although in the case of the turbo-reaction engine it was wetted by gases at about 650°C. at full power, had given no trouble as regards deformation of the arms and misalignment. The sheet metal cylinder surrounding the turbine (and which was part of the bearing) had given them some trouble because of deformation when cooling, leading to rubbing at the blades. This had been cured by reinforcing the sheeting in the way of the moving blades, and making it independent of the rest of the bearing at this section.

**Mr. Lindsey:** 1. The quoted consumption figure of 0.77 lb./h.p./hour at sea level applied to 500 m.p.h. and not to static conditions. Under the latter, consumption was, unfortunately, distinctly higher. With the very moderate temperature (550°C.) ahead

of the turbine, and a compression ratio of 3.6, this figure of 0.77 lb. corresponded to a compressor efficiency of 85 per cent., a turbine efficiency of 88 per cent., and a combustion chamber pressure loss of four per cent. These characteristics were actually obtained on test at static conditions.

2. They confirmed the efficiency figures obtained by the Jumo compressor as quoted in the lecture, as well as those obtained by their own turbo-reaction engine compressors, which they had pointed out to Mr. Davidson (over 87 per cent. up to 3.3 compression ratio, and 82-83 per cent. for a ratio of 3.7 with eight stages).

4. (*b*) The theoretical combustion rate for vaporisation combustion was really 4,800 h.p./cu.ft. at atmospheric pressure.

(*c*) They agreed with Mr. Lindsey on all the difficulties with vaporisation combustion which he mentioned. But for the pumping of the vaporiser vapour up to the grid entry, they noted no special difficulty as they were mixing air with petrol, and this air was at a pressure appreciably higher than that in the chamber. From the point of view of matching, this excess of pressure allowed them to get a rapid response of combustion to the controls, as they were simultaneously acting on the air and petrol deliveries.

# THE DEVELOPMENT OF THE ARMSTRONG SIDDELEY MAMBA ENGINE

by

W. H. LINDSEY, M.A., A.F.R.Ae.S.

## INTRODUCTION

THE Mamba engine has now been in existence some two-and-a-half years and in that comparatively short period of time it has been developed to the stage of being a type tested engine with over 5,000 hours test bed running and 100 hours flying as a background.

The purpose of this paper is to give a brief account of the progress of the development and of the many problems which have been met and overcome during the period. Because of the many aspects of the development work it is not possible to deal in great detail with any particular item but rather to present the over-all picture, from the original design conception to the complete power plant of to-day.

## HISTORY

In 1945 Armstrong Siddeley Motors Ltd., were in the early stages of the development of an 850 h.p. radial piston engine designed for civil and trainer applications which were then planned and were asked by the Director of Engine Development to look into the design of a gas turbine propeller engine to do the same job. As it was necessary to provide the 850 s.h.p. for take-off anywhere, the gas turbine engine had to be designed to give the power at about 5,000 ft. altitude under tropical conditions, which fixed the standard I.C.A.N. sea level power at 1,000 s.h.p.

The 761st Lecture read before the Society—on 25th November 1948 at the Institution of Civil Engineers, Great George Street, London, W.1. In the Chair, the President, Dr. H. Roxbee Cox, D.I.C., F.R.Ae.S., F.I.Ae.S.

Mr. Lindsey is Deputy Chief Engineer of Armstrong Siddeley Motors Ltd.

The project design proceeded on these lines, special emphasis being placed on light weight and small diameter as it was thought that these two features should be the main attraction of the gas turbine design and, if successfully attained, would more than counteract the inevitable increase in fuel consumption as compared with the rival piston engine. The project design was completed in the autumn of 1945 and looked indeed attractive. The diameter was only 27 in. as compared with 50 in. for the piston engine and the estimated weight was 650 lb. compared with 980 lb.

As a result of the design study it was decided to proceed with a final design and manufacture of prototype engines and this work was actively pursued with only minor alterations to the project design.

In April 1946 the first engine was installed on the brake ready for its first run. This engine weighed 707 lb. The increase in weight was largely caused by alterations to the project design to facilitate manufacture and avoid some "unknowns," which might have interfered seriously with the early completion of the prototype engines.

The first runs were disappointing, largely because of compressor troubles which will be discussed later, but testing was continued at very low powers to test mechanical features while the compressor was being put right. As a result of these tests a radical mechanical change was made to the engine to incorporate a centre bearing. The engine first achieved a power figure approaching its design value in December 1946, when a shaft power of 1,013 h.p. was recorded.

The next major item to need attention was the reduction gear and some busy months were spent before the gear would run satisfactorily for long periods. By May 1947 this

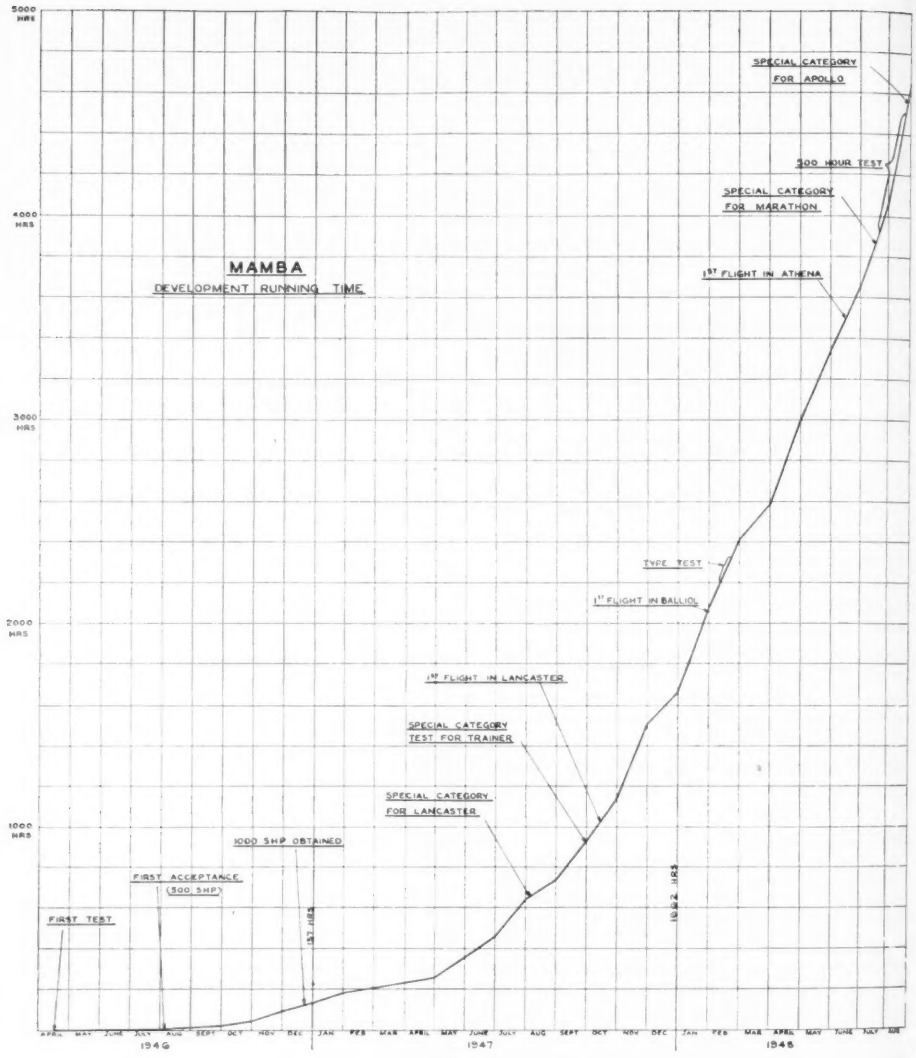



Fig. 1.
Mamba development running times.

trouble had been largely overcome and development running times showed a heartening increase. Fig. 1 shows a plot of running times for the engine during its development period.

The slow start when compressor and performance difficulties were encountered is clearly seen, as also is the rapid increase in the rate of development running when the reduction gear troubles were overcome. The curve is typical of the running experience in new engine types.

Development then proceeded rapidly, the longer running periods made possible by the elimination of major troubles bringing to light in the usual way a host of minor

troubles, all of which had to be overcome in turn. Undoubtedly the greatest of these secondary troubles was the development of a combustion system which would last long enough to complete a 150 hr. type test without attention. This will be discussed in more detail under its own heading.

The next milestone was the installation of an engine in the nose of a Lancaster aircraft and this flew in October 1947. A flying test bed of this type is of the utmost importance in solving troubles peculiar to an aircraft, as distinct from a test bed installation, and in providing a satisfactory method of control in flight which, in the case of the gas turbine engine, involved new and difficult problems which will be discussed later.

In February 1948 a Mamba engine completed successfully a final 150 hour Military and Civil Type Test and thus became established as an aero-engine.

Since that date development has proceeded on various versions of the engine for military and civil applications, and the Mamba has flown successfully in the Boulton Paul Balliol trainer and the Avro Athena trainer. A civil version of the engine has been installed in the twin-engined Miles Marathon and the four-engined Armstrong Whitworth Apollo air liners.

A recent development of great interest is the re-design of the compressor and turbine to give increased power. Without altering the external dimensions of the engine it has proved possible to increase the air consumption of the engine by 26 per cent., thus raising the basic shaft horse power rating to 1,260 s.h.p. This engine, which has been called the Mamba 2, is just starting its development life, but as only the aerodynamic design has been affected its mechanical reliability should be maintained. Early performance testing has already shown that the new engine can develop at least 1,300 s.h.p. and as there is no change in size and practically no change in weight, the Mamba 2 will provide an interchangeable replacement for the Mamba 1 in any installation without any weight penalty.

The additional power available will also allow the Mamba 2 to be used in other aircraft for which the Mamba 1 would be insufficiently powerful and the saving in weight and installed drag over a piston engine of equivalent power will undoubtedly open up a wide field of application for this new version.

The foregoing historical account has been necessarily brief and it is intended in the rest of the paper to describe in more detail the work that has been done on the more particular aspects of the development work. Before embarking upon this, it would be of interest to see a general arrangement of the Mamba engine as originally designed (Fig. 2) which was the starting point.

The Mamba in its present form is fairly well known to-day and it differs only in some mechanical aspects from the original conception shown in Fig. 2. It was a single shaft "straight-through" engine having an axial flow compressor of 10 stages, six can-type combustion chambers and a two-stage turbine. Power was taken from the front end of the compressor at 14,500 r.p.m. and this speed was reduced by a compound epicyclic gear to 1,640 r.p.m.—an over-all gear ratio of .113. The estimated power was 1,010 s.h.p. plus 320 lb. jet thrust for a fuel consumption of 104 gals. hour.

The rotor was mounted originally in two bearings, a double angular contact ball type thrust bearing at the front of the compressor and a single roller bearing immediately forward of the turbine.

The rotor consisted of a steel drum, built up from two main components, the compressor drum and the tail shaft, to which were attached the driving member at the front and the turbine stub-shaft at the rear. Each row of compressor blades was mounted on two steel discs fitting on the drum and riveted together at the rim, the "T" form blade roots of light alloy being sandwiched between the two discs at the rim and riveted with them. The resulting triangulated structure was both stiff and light. The hubs of the discs were dogged together to transmit the drive from stage to stage.

The stator blades were mounted in axial dovetail slots in loose half rings held in two halves of the forged aluminium stator casing by means of spacer rings bolted through to the outside of the casing. Originally the stators were shrouded at the tips, the shrouds consisting of two half rings of aluminium held in position by riveting over the ends of small extensions to the stator blades, which passed through slots in the rings. Air was to be prevented from leaking back across the stator row by controlling the axial clearance between the stator shrouds and the ring formed by the rotor blade platforms when assembled in the discs.

At the high pressure end of the compressor was bolted the forged diffuser casing, which supported the steel engine mounting

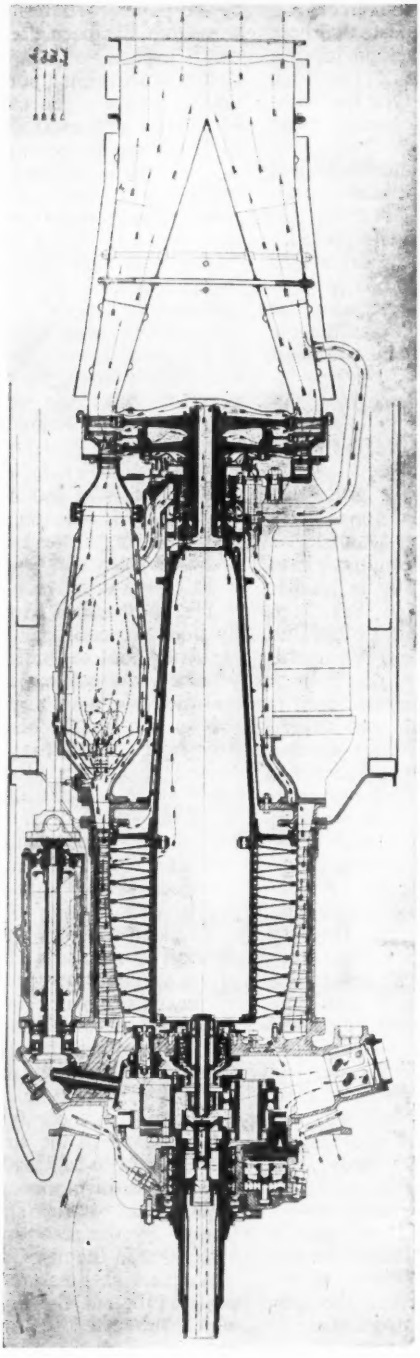


Fig. 2.
Original Mamba design.

ring. To the after side of the diffuser casing was bolted a cast aluminium combustion chamber manifold which divided the air into six portions and formed the entry to the combustion chambers. The main steel backbone of the engine was attached to the inner diameter of the diffuser casing and the turbine manifold was supported from the after end of this tube.

The turbine manifold consisted of a single piece steel casting which was supported from three swinging links, as shown in Fig. 3. These allowed for expansion of the manifold and at the same time retained the necessary concentricity.

The first row turbine nozzles were fixed in the manifold itself and the turbine stator rings and were bolted to the manifold and carried the second row nozzle ring. This nozzle ring was formed by riveting the double shrouded blades to a steel disc at their inner ends, the outside shrouds forming a ring which fitted into the stator rings and was prevented from rotating by engaging dogs formed in the shrouds and the stator rings.

The turbine rotor assembly is shown in Fig. 4. It consisted of two separate discs mounted on a large bolt, the high pressure disc driving through a stub shaft splined to the main rotor shaft and attached to the disc by a row of bolts. The second disc was located relatively to the first by a series of radial pegs. Air was prevented from leaking round the second row nozzle system by a labyrinth formed at the inner diameter of the second nozzle diaphragm.

Figure 4 also shows the cooling arrangements for the discs and the rear roller bearing. Three air cooling supplies were used for the discs; a high pressure supply was piped from the end of the compressor and led up to front face of the high pressure disc and out into the main stream after the first row nozzles; an intermediate pressure supply was taken through holes on the compressor drum and led between the discs, and a low pressure supply taken from the air which leaks past the compressor sealing glands was exhausted via the back of the low pressure disc. A separate supply of air piped from an intermediate compressor stage was used to cool the bearing by passing over and under the bearing housing and thence into the air stream, cooling the rear of the second stage disc.

The reduction gear was driven by way of a quill shaft from the front end of the compressor and consisted of a straightforward compound epicyclic gear, which will be referred to later.

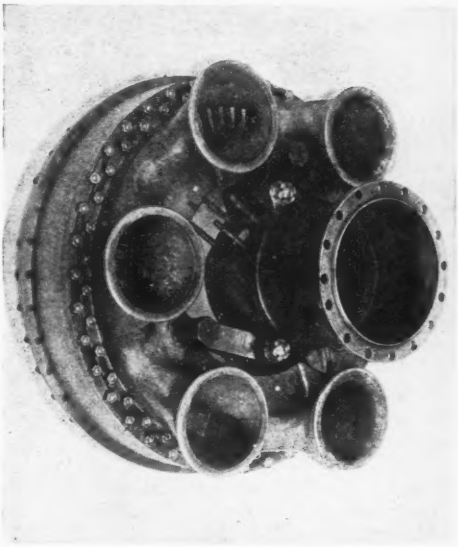


Fig. 3.
Turbine stator mounting, showing swinging ends.

This was the original engine. The following sections describe how it had to be modified in the light of running experience to become the Mamba engine of to-day.

## MECHANICAL DESIGN DEVELOPMENT

Although during the two-and-a-half years of development work there have been a multitude of minor changes to the mechanical details of the engine, only two major alterations to the original conception of the engine proved necessary. These were:

(*a*) The incorporation of a centre bearing.

(*b*) The modification of the reduction gear to eliminate tooth meshing frequency vibrations.

The need for the first of these modifications was quickly apparent. During the early running of the engine while we were still in trouble with the compressor, fouling of the compressor blades on the casing was experienced at the high pressure end of the compressor. This was originally thought to occur because of whirling of the rotor drum assembly at high speed, due to rotor out of balance. Calculations and rig tests did not

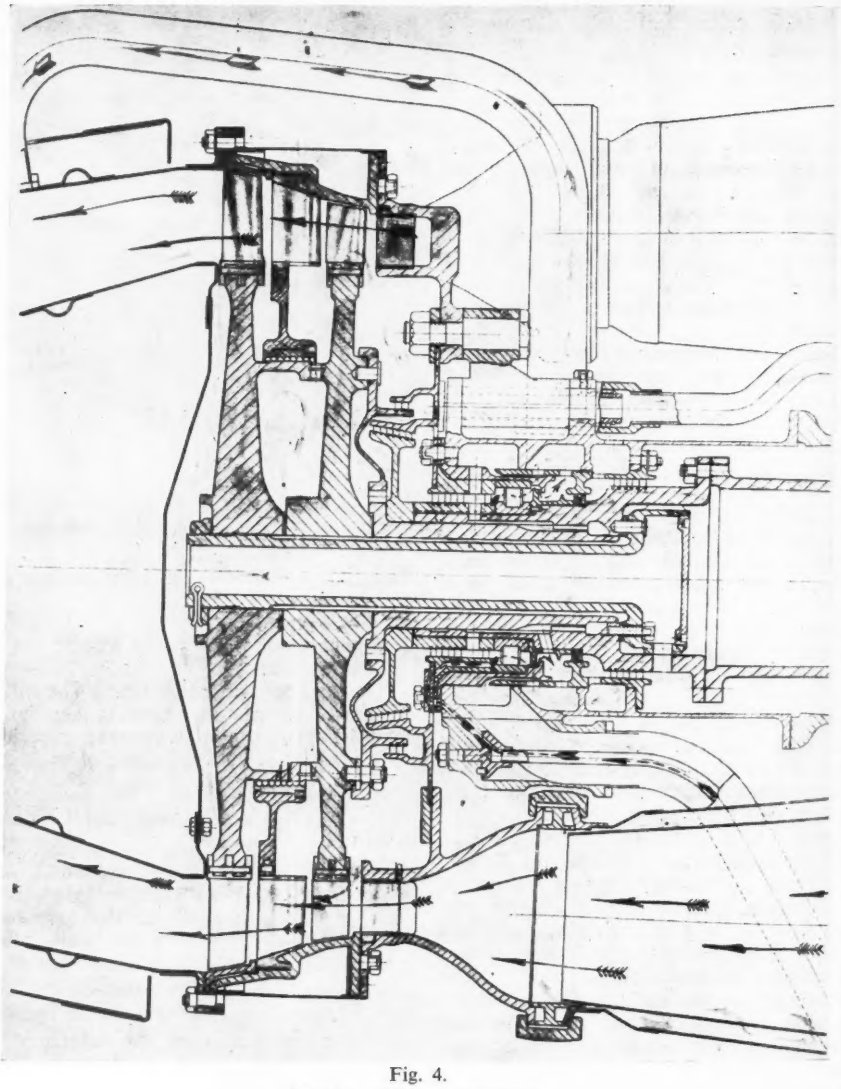


Fig. 4.
Mamba turbine arrangement.

support this theory and a closer examination of the main engine behaviour brought to light the fact that trouble occurred immediately after a shut down. It became apparent that while stationary after a run, the normal rise of hot gases to the upper half of the engine caused a sufficiently large temperature difference between the top and bottom of the engine to cause the stator assembly to bow. This reduced the clearance between stator and rotor in the centre of the engine and resulted in a foul on re-starting.

The only satisfactory cure was thought to be the introduction of a centre bearing and some degree of articulation in the rotor system between the compressor and turbine

end of the engine. This meant a major re-design and at first sight it seemed that a severe weight penalty would be incurred. This had to be faced and the re-design was energetically pursued. The suggestion that in the re-design the diffuser casing, the combustion chamber manifold, and the mounting ring could all be incorporated in a single casting which would also house the new bearing, was successfully adopted.

While design work was proceeding a temporary scheme was introduced adding the centre bearing assembly to existing engines in order to obtain experience in running, both as regards the cure of the original trouble and the behaviour and lubrication of the new bearing. The bearing chosen was the same type as the turbine roller bearing and it was decided to lubricate and cool the bearing by a positive oil supply fed from the pressure pump and scavenged by means of an extra scavenge pump.

Preliminary tests showed that the new bearing cured the trouble and that an oil feed of about 20 gals. per hour was sufficient to keep the bearing at a reasonable temperature.

The final scheme incorporating a new centre section casting looked most promising and apart from much difficulty in the detail design of the complicated casting, gave little trouble. The details of the casting were very troublesome indeed and more than one design change had to be made before the weight of the casting, as distinct from the calculated weight as designed, could be brought within the very tight weight requirements.

The lubrication system also worked well and apart from a later modification, which eliminated the separate scavenge pump and allowed the scavenge oil to drain into the main gear box, has remained unchanged since its introduction.

The next obstacles in the way of trouble-free mechanical behaviour were associated with the reduction gear.

Fortunately many lessons had been learned from the Python, experience with which was being obtained during this period and the problem could be tackled with confidence. As originally designed the gear was a compound epicyclic gear, the sun gear of which was driven by a quill shaft from the front end of the compressor and had 16 teeth. The sun gear meshed with three planet gears, each having 35 teeth which were mounted in roller bearings in a built-up planet cage, the front half of which incorporated the airscrew shaft. Integral with the planet gears were three satellite gears having 15 teeth which meshed with a stationary internal gear having 54 teeth, the whole gear train giving a ratio of .113:1. In the first instance all teeth were of the stub type.

The 54 tooth internal gear, although prevented from rotation, was not fixed. It was located in a fore and aft plane in the gear-case and allowed to centralise itself on the three satellite gears. It was fitted with three equally disposed sockets round its periphery into which fitted three dumbell shaped rods. These fitted at their others ends into sockets in three bell crank levers which transmitted the torque reaction to three pistons working in cylinders supplied with pressure oil. By means of special ports in the cylinders it was arranged that the oil pressure balanced the thrust from the bell crank levers and thus the oil pressure in the cylinders was a function of the torque through the gear.

Vibration troubles were soon apparent during engine running, with the usual symptoms of fatigue failures of compressor blades, tabwashers and the gears themselves, and severe fretting of all the mating surfaces in the torquemeter mechanism. Trouble was encountered especially in the internal gear which failed adjacent to the torquemeter sockets.

Critical examination of the natural frequencies of the failed components showed the trouble to originate in the tooth meshing. During the meshing of two gears of the type we used the load, for a time, is carried solely on one tooth in each gear. The load carried causes the tooth to deflect and hence the teeth just about to come into mesh are slightly out of pitch and therefore, when they do engage, there is a distinct shock which can cause a vibration of tooth meshing frequency. The cure is to relieve the gears at the tip and root, thus forming a wedging action on engagement. This relief, however, effectively alters the profile of the tooth, which is no longer of true involute form.

Thus, if the relief extends into that portion of the tooth which is carrying the load during the period of single tooth contact, the angular velocity of the driven gear cannot remain uniform. The accelerations caused by this factor are such as to involve enormous loads and in fact, the discrepancies are taken up by further tooth deflection accompanied by vibration.

In some earlier work a cure was found by substituting full depth teeth for stub teeth. Fig. 5 shows how this substitution enables

relief to be applied to full depth teeth without altering the involute form over the region of single tooth contact. By retaining correct tooth form in this region and just the right amount of correction outside, vibration can be eliminated. Any errors will introduce some vibration and its intensity will vary with the square of the tooth meshing frequency. As this frequency for the sun gear train in the Mamba gear was very high it was thought that gears could not be made accurately enough to eliminate trouble in this train by resorting to full depth teeth. The tooth meshing frequency was 3,430 cycles/sec.

Accordingly, full depth teeth were used in the second or internal gear train only and the sun gear train was re-designed, using single helical gears for sun gear and planets. This compromise avoided grinding a helical internal gear and eliminated the necessity of controlling to fine limits the axial spacing of the satellite and planet gear wheels on this shaft.

Apart from purely manufacturing difficulties, the use of helical gears introduced the problem of absorbing thrust loads on both the sun and planet gears. The former was simple, as the thrust was taken through the quill shaft to the main compressor thrust bearing and under normal conditions was arranged to reduce the load on this bearing.

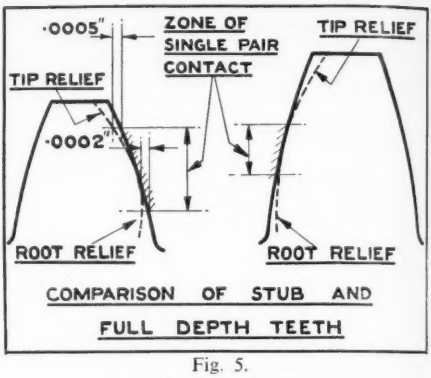



Fig. 5.
Tooth profile diagram.

The planet wheels were a much more difficult problem as journal and thrust bearings had to be provided in the space occupied by the existing roller bearings. Many weeks of hard work were needed and many disappointments were experienced before a solution was found. Eventually, the solution proved to be the modification of existing roller bearings, which were cageless, to cage type bearings with specially designed cages, the addition of a ball bearing to take the thrust only and the provision of positive lubrication to the whole bearing system.

The special cages were necessary because the planetary motion of the bearings caused the cages to work in a centrifugal field of force. The cages had to be light and strong and to be located on the bearing races in such a way as to transmit their own centrifugal loads without wear. They were eventually made from solid aluminium forged rings, the roller spaces being broached and the cages were made a running fit on the inner races of the bearings.

The whole of this gear development occupied over three months and was eventually entirely successful. The lessons learned have enabled similar gears to be designed which have worked first time.

It is now believed that the principles of high speed gears of this type are fully understood and that this problem, which was once quite rightly deemed to be the big "if" in propeller-turbine engines, has been permanently solved.

These were the main mechanical difficulties with the Mamba. Because of the extensive

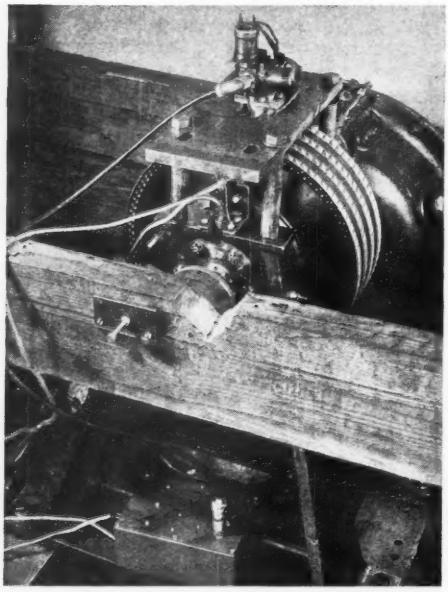


Fig. 6.
Disc spinning rig.

rig work and past experience on earlier engines, the problems of turbine and compressor bearing reliability never arose on this engine and indeed, bearings are now regarded as thoroughly reliable components —although they are required to work at speeds and loads far in excess of their makers' original specifications.

One interesting problem was purely aerodynamic in origin and will be discussed later. It constituted transforming the essentially disc type of compressor construction into a drum type, as far as its external form was concerned.

While this provided a convenient aerodynamic cure for our trouble, it set a somewhat difficult stressing problem as the shroud rings were not capable of carrying themselves and had to rely upon some support from the blade root fixings, which in turn increased the loading on the compressor discs. Although the theoretical stressing figures looked fairly reasonable, we were doubtful about their validity and we decided to spin a representative set of discs and shrouds.

Figure 6 shows the test set up and very careful figures were taken for the expansion of both the discs and the shrouds at speeds up to 18,000 r.p.m., the rated maximum speed of the engine being 14,500 r.p.m. No permanent set occurred even due to this overspeed and at the full speed of 18,000 r.p.m. the maximum expansion at the centre of a shroud ring was .002 in. on the diameter, the shrouds actually bowing about .0035 in. in the centre.

These results have been confirmed in engine running and except in the few instances where we have had an accidental foul between the shrouds and the stator blades, the shrouds have given us no mechanical trouble.

## COMPRESSORS AND TURBINES

The extent to which a gas turbine engine fulfils its design performance as regards output and specific consumption, depends largely upon the aerodynamic design of the compressor and turbine. Historically the inability to design a compressor efficiently was one

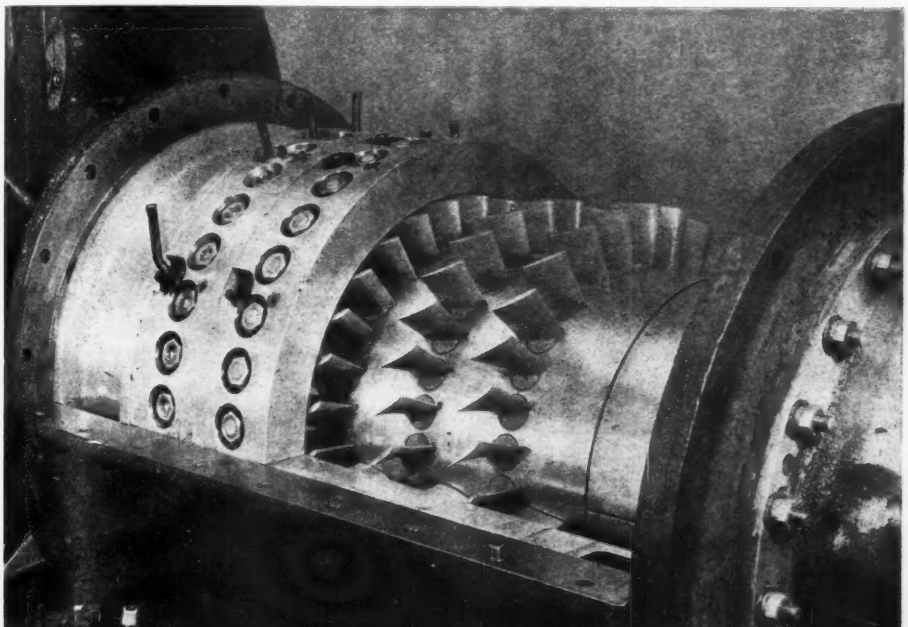


Fig. 7.
Research compressor.

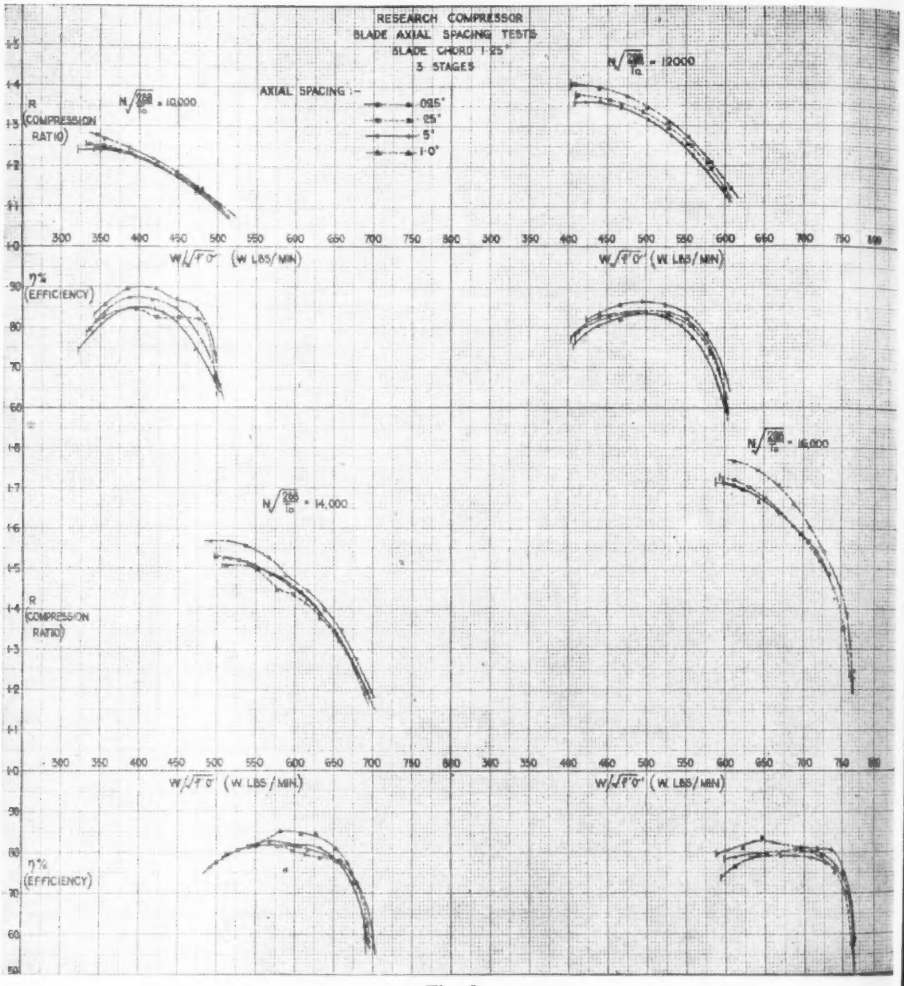



Fig. 8.
Effect of compressor axial spacing.

of the major obstacles in the achievement of a successful gas turbine engine; the other obstacle was the inability to find turbine steels which would withstand the high temperatures necessary.

Before starting upon gas turbine work, in 1943 much basic work had been done on the design of axial flow compressor and in the preliminary review of the situation it was decided to concentrate on the axial type of compressor. The reasons for this decision were that there were definite indications that axial flow compressors could be made more efficient than the centrifugal compressors and that they were fundamentally a better shape for inclusion in an aero-engine than a centrifugal compressor, as they were smaller in diameter and greater in length. Preliminary work had also shown that their major drawback for use as piston engine superchargers was their steep compression ratio and efficiency characteristics, but this would not necessarily be a handicap when used as components of a gas turbine engine.

Among the people working on the design of axial flow compressors were the active team at the Royal Aircraft Establishment, Farnborough, and it was from them that the latest information on the art of axial flow compressor design was obtained when we started on the A.S.X. engine. The resulting compressor behaved very successfully after only minor aerodynamic alterations and although the design was not very bold, the success of this compressor confirmed the belief that the axial flow unit was the type to adopt.

The basic A.S.X. compressor, designed to give a compression ratio of 5:1 in fourteen stages, formed the basis of the Python compressor and although it has been much improved in details in the intervening years it has remained basically unaltered. From full-scale compressor tests and engine tests the knowledge of axial flow compressor design increased, although because of the lack of full-scale compressor test facilities at the works, the compressor tests had to be done at the M.O.S. rig at the Northampton Power Station.

Domestic resources only amounted in those days to a single rig of 450 b.h.p. capacity,

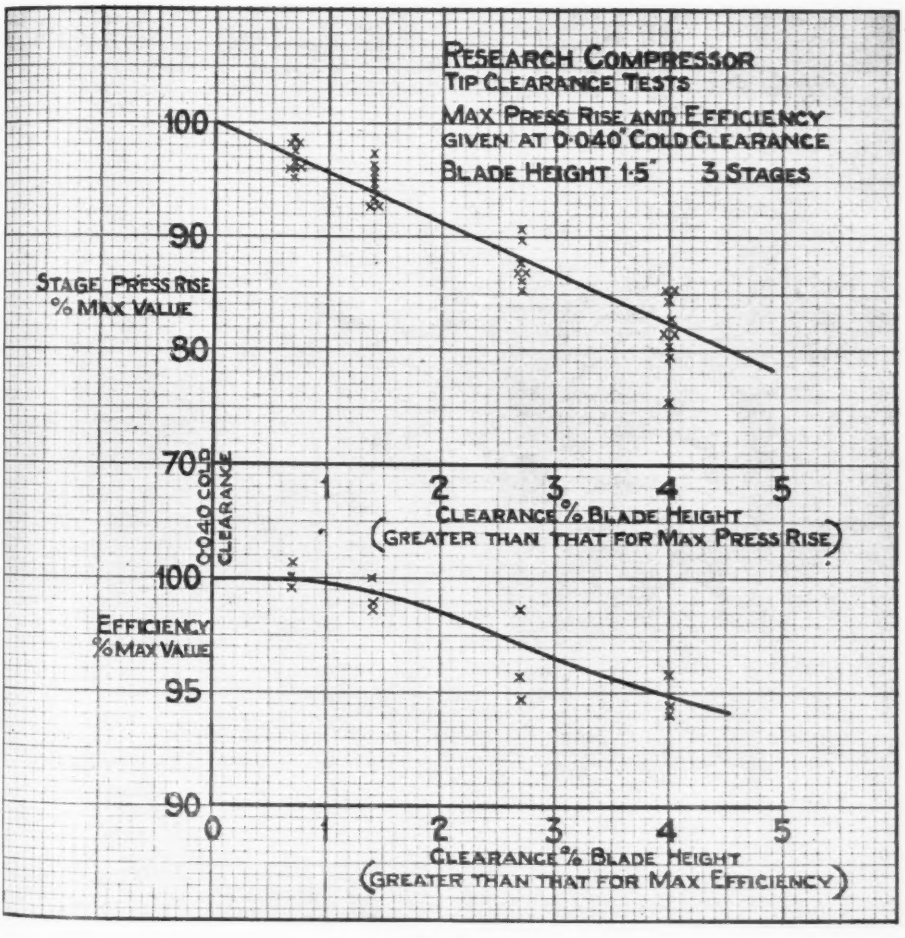



Fig. 9.
Effect of compressor tip clearance.

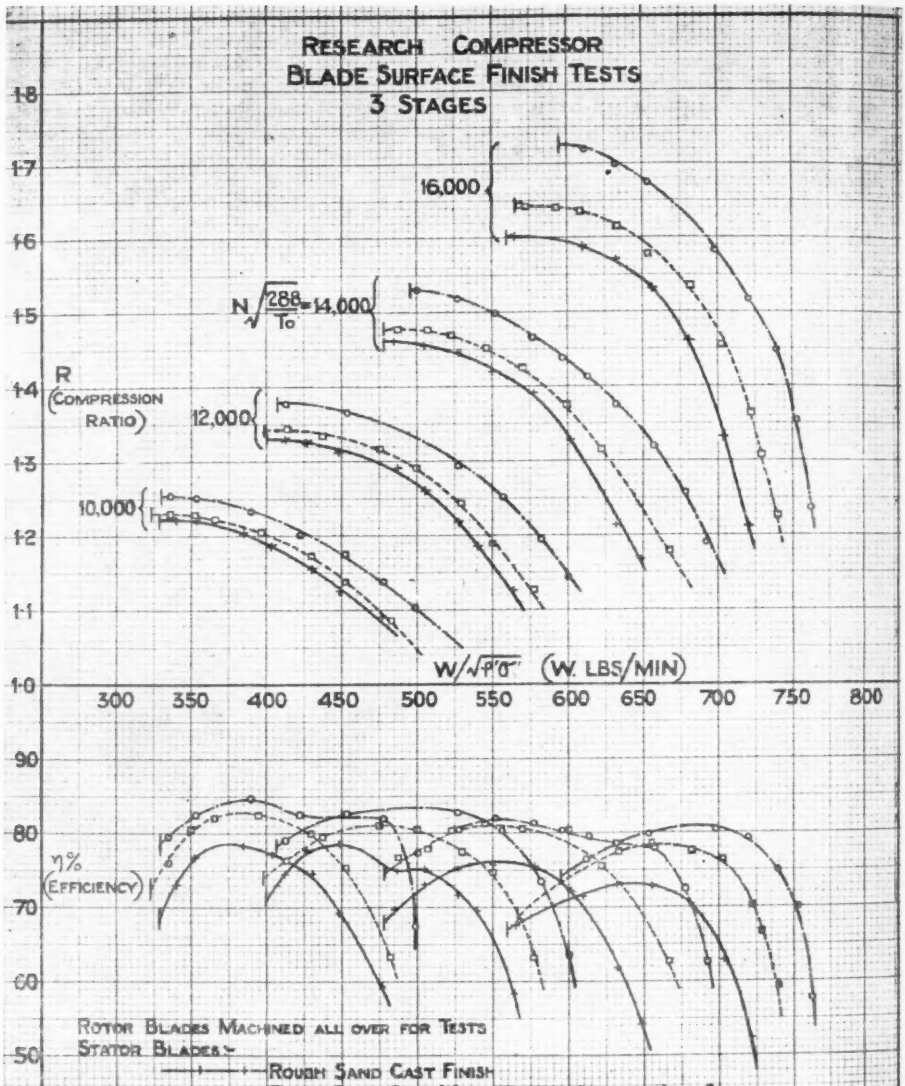



Fig. 10.
Effect of compressor blade finish.

which was used by constructing a small research compressor on which fundamental work could be done.

Much interesting information was obtained from running this small compressor. Fig. 7 shows how it was designed. It will be noticed that the compressor can be run with either one, two, three or four stages and that alterations can be made quickly to blade angles, axial blade spacings and number of stages

under test; even the complete reblading of the compressor was quite a short job. Work continued on this compressor, exploring such interesting questions as:—

(*a*) What was the best axial spacing for a compressor.

(*b*) How much tip clearance we could use without losing performance.

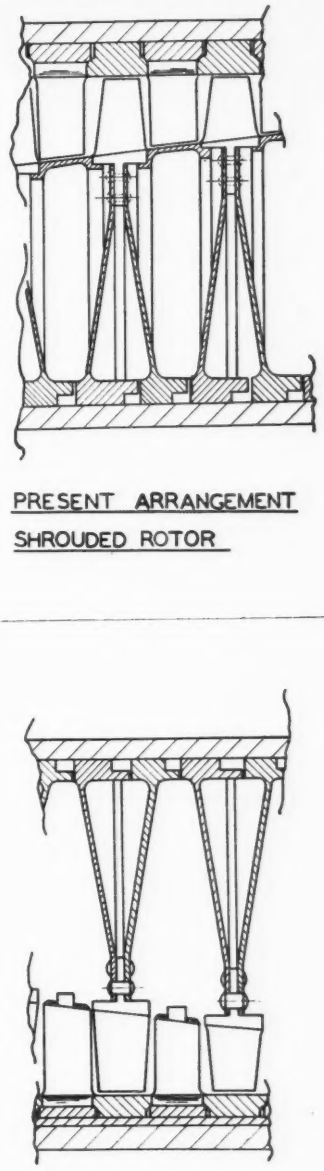
(*c*) What was the effect of blade finish.

Figures 8, 9 and 10 give the answers to some of these questions obtained from work on the small compressor.

All these experiences on the experimental compressor tests, expanding information of a fundamental nature which has been obtained during the period at the Government Establishments, enabled the next axial flow compressor for the Mamba to be made much more compact and lighter. The Mamba compressor was to have the same compression ratio as the A.S.X., but was designed for a mass flow of only 13½ lb. per second, against 50 lb. per second for the A.S.X. compressor. The increased knowledge on the subject allowed a reduction in the number of stages for this compressor from 14 to 10, thus designing for an average temperature rise per stage at full speed of nearly 21°.

In many other aspects the Mamba design was a radical departure from the A.S.X. design; the rotor was of disc type construction to allow for higher rotational speeds and the original design called for shrouded stator blades. The blading design itself was of the medium stagger type. For ease of manufacture the stator blades were made with untwisted sections which led to blading approximating closely to what is known as half vortex blading. This term merely means that the tangents of the air angles at any point are the arithmetical means between those which would obtain for free vortex design and those which would obtain for constant reaction design. The blades are produced by stamping accurately to form, no machining being required except for the root fixings.

As with the A.S.X. engine, no time or facilities existed for testing the compressor before the date for running the first engine. Some new compressor test rigs capable of testing the Mamba unit were being laid down, but the engine itself was ready before these were available and it was decided to carry on in the same way as had been done with the A.S.X. engine. Unfortunately, this policy did not meet with the previous degree




Mamba compressor, 5th and 6th stages.

Fig. 11.

Stator shroud arrangement.

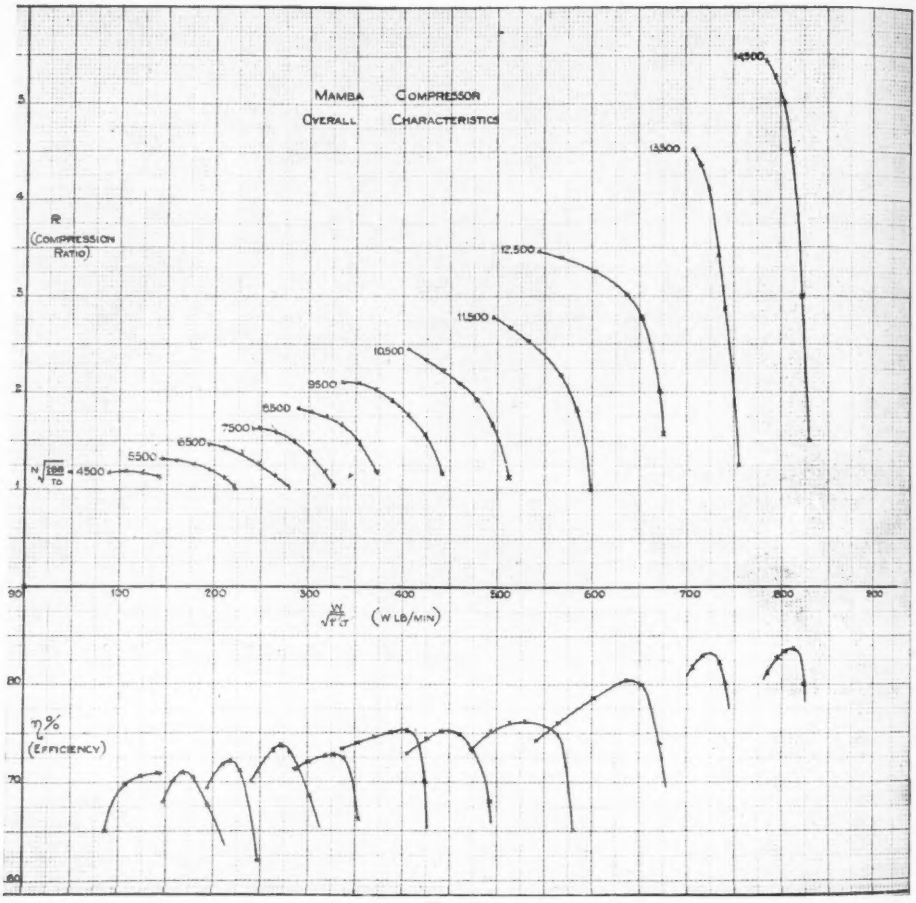



Fig. 12.
Mamba compressor characteristics.

of success, in fact on the first run the compressor performance was so disappointing as to preclude any possibility of the engine working without a radical improvement in the compressor performance. The performance was so bad that all the ratings that could be obtained on the main engine test bed were figures for the outlet pressures and temperatures for the speed range from 11,000 to 14,500 r.p.m. These showed that the maximum compression ratio at full speed was nearer 3½:1 than 5:1.

The position was so serious and the matter so urgent that the delay that would occur from waiting for either the new rig to be ready or for the necessary arrangements to be made to test the compressor elsewhere, could not be allowed and tests were made as far as possible on the 450 h.p. rig.

A serious review of the whole compressor design was undertaken and it was decided that the only feature of the compressor which could be causing such a catastrophic loss in performance was the design of the stator blade shrouds. Fig. 11 shows this shroud arrangement and the theory was that the axial sealing of these shrouds was inadequate and that the re-circulation around the very small stator blades was completely upsetting their performance. To check this, cylindrical distance pieces were inserted between the stages, as shown in Fig. 11, thus converting

a disc type compressor and reverting to the A.S.X. type of unshrouded stator blades. This modification caused an immediate and heartening increase in performance and in one stride we had increased the compression ratio from 3½:1 to something over 4½:1. Stage-by-stage performance calculations and measurements showed that the remaining discrepancy was caused by the inadequate pressure rise in the last stages of the compressor and these were cured quite quickly by minor alterations in blade setting angles.

Within three months of starting work on the investigations, the compressor was producing its design performance. The characteristics of the present Mamba compresor are shown in Fig. 12.

The success of the experimental work on the Mamba compressor gave encouragement to seek further improvement. The design of the compressor, with the last four stages of equal height, suggested a simple method of increasing the throughput of the compressor and hence the engine, with consequent increase in engine power. The scheme suggested was to design two new low pressure stages to be inserted in front of the compressor and to remove the last two stages, thus maintaining the compression ratio, increasing the outlet velocity and effecting a theoretical increase of 26 per cent. in the air mass flow. As the new first two stages would have the same outside diameter as the original stages and merely a reduced root diameter, the outside casings would not need to be altered. Fig. 13 shows the scheme diagrammatically.

Work began on these lines and the new compressor was very successful. Fig. 14 shows the resulting characteristics and it can be seen that the 26 per cent. increase in mass flow was achieved and the efficiency at the design point was also increased by 1½ per cent.

This new compressor formed the basis of the Mamba 2 engine now undergoing development testing. The accuracy of the forecasted performance is a tribute to the greater understanding of axial flow compressor design which has resulted from past experimental and theoretical work on the subject.

It is interesting, from an experimental point of view, that the vast majority of work was done with completely inadequate equipment and that throughout the whole of the

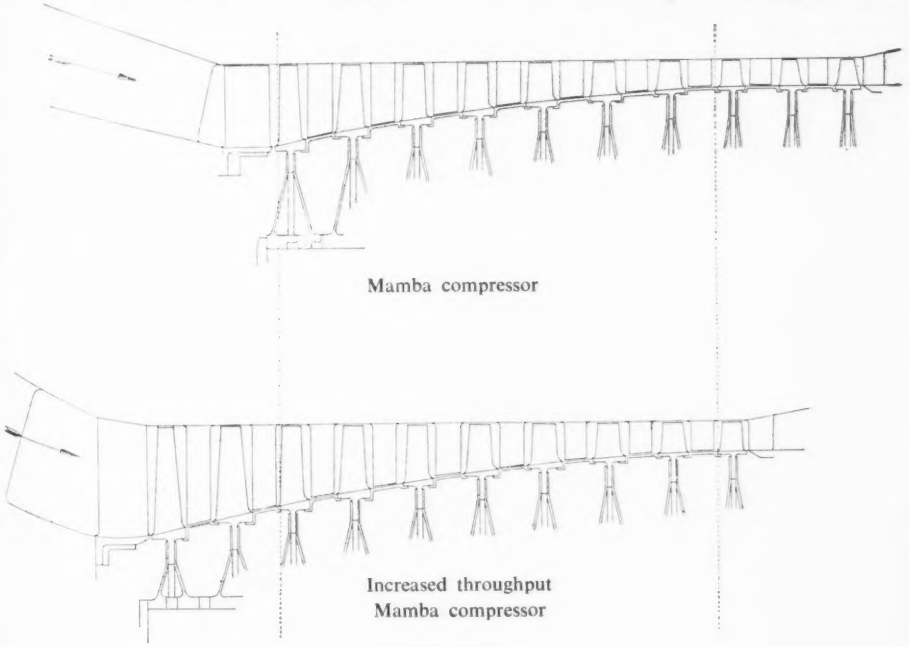



Fig. 13.
Design of increased capacity Mamba compressor.

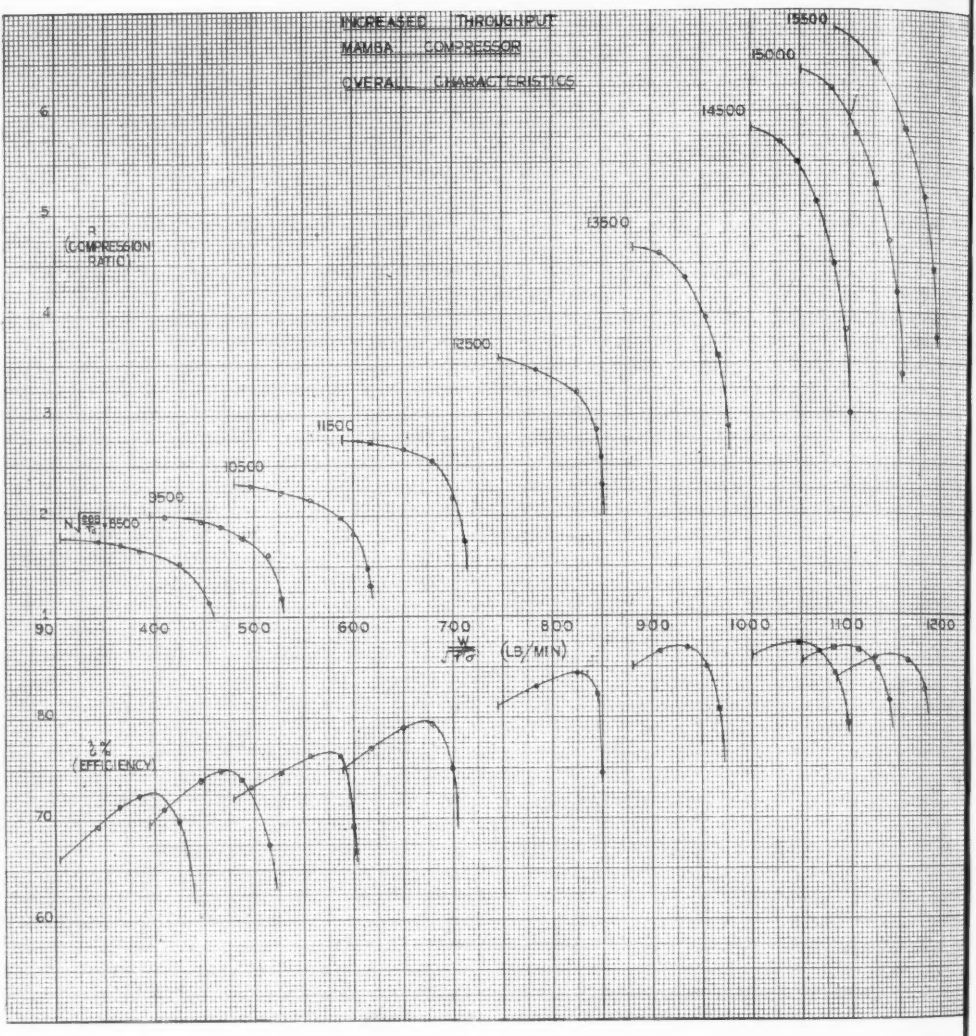



Fig. 14.
Characteristics of increased capacity Mamba compressor.

performance investigations at this stage it had not been possible to run the compressor at its design speed on the rig. When the time came when the full speed could be achieved, the conclusions obtained from our original tests were amply confirmed.

Work is still proceeding on performance testing of these compressors, both on the new 750 h.p. rigs and on the compressor test rig at the National Gas Turbine Establishment at Whetstone—although the improvements now being sought are of a minor, but still important, nature.

If the maximum performance is to be obtained from a gas turbine engine it is exactly these minor improvements in the performance of an already good compressor which will make the difference between a

reasonably good engine and an engine with an outstanding performance. The success in the early stages with improvised methods of testing has not in any way altered the conviction that if rapid progress is to be made in the design of gas turbine engines, it is esential to possess adequate compressor and turbine test facilities.

In addition to the first 450 h.p. rig, two experimental rigs of 750 h.p. each now exist which are of immense value for experimental purposes and which can be used quite successfully for calibrations of compressors up to the size of the Mamba. For larger compressors a bigger rig is essential and plans are in hand for the provision of a large turbine and compressor test station which will be driven by a steam turbine developing a maximum of 11,000 h.p.

While everybody realised from the start that compressor development was essential if any results were to be obtained from gas turbine engine development, turbine performance did not receive the same attention. The reason for this was the belief that because the air flow through a turbine is fundamentally of an accelerating character, the aerodynamic problems involved were not nearly so difficult. This is true to the extent that to produce a multi-stage turbine with an efficiency of over 80 per cent. is not difficult, but to achieve the maximum possible efficiency from a turbine is now realised to be just as difficult as achieving the maximum efficiency from a compressor. As soon as it is realised that for every increase of one per cent. of turbine performance, the shaft horse power obtainable from a gas turbine propeller engine can be increased by three per cent. for the same fuel consumption, the importance of obtaining the best possible turbine efficiency will be understood.

Unfortunately, turbine test rigs were even more scarce and more difficult to install than compressor test rigs and so far, little rig work has been done on the development of turbines. Despite this, some very good turbines have been made, especially of the single-stage type, but the efficiency of two and more stage turbines still leaves much to be desired. Improvements have been made on the Mamba turbine from results obtained from engine testing, but this is a slow and not very certain process and adequate facilities for the performance testing of turbines themselves are included in the new compressor test station.

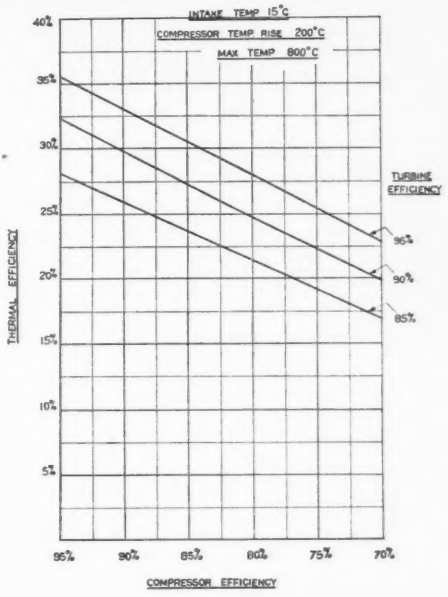



Fig. 15.
Gas turbine.
Effect of compressor and turbine efficiencies on thermal efficiency.

It is thought that by a course of intensive experimental investigations into turbine characteristics, improvements of the order of five per cent. in existing turbine efficiencies can be achieved.

Figure 15 shows some curves which demonstrate the prizes to be obtained for comparatively small increases in turbine and compressor efficiency. If enough progress can be made in these directions, the specific fuel consumption and specific output of gas turbine propeller engines can be improved to an extent which will go a long way to removing their present disability of rather high fuel consumption.

## COMBUSTION

As originally designed, the Mamba engine was fitted with six combustion chambers designed and manufactured by Joseph Lucas Ltd. The chambers were of the now familiar design and Fig. 16 shows a cross-sectional arrangement of one. All our early running was made using this type of chamber,

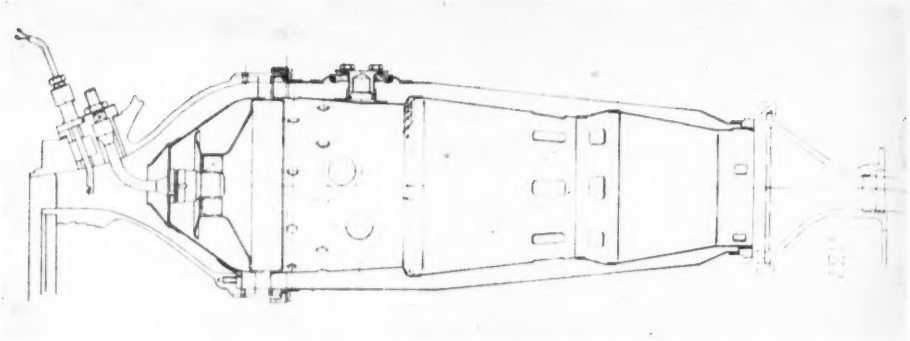


Fig. 16.
Lucas combustion chamber.

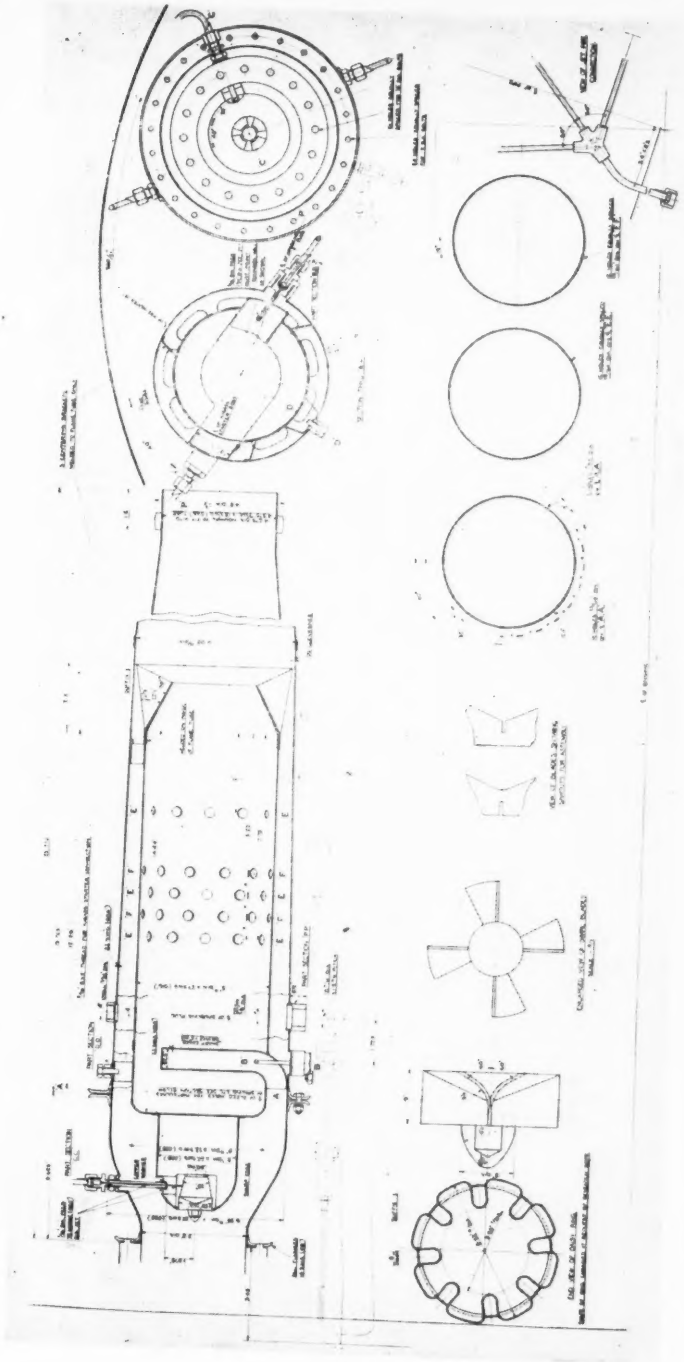
although modifications were introduced during development to improve reliability. This type of chamber is now well known as it constitutes to-day what might be described as the "Standard" chamber for most British gas turbine engines and its development has been described elsewhere much more ably than could be done here.

The section will be confined therefore to a description of the development of a combustion chamber for the Mamba which works on the principle of burning a vaporised, as distinct from an atomised, fuel. This is a subject which has interested Armstrong Siddeleys from the early days and the resulting development work has been both interesting and successful.

Work on combustion problems formed part of the very earliest work that was done on gas turbine engines. The original work was of an exploratory character and was done with the crudest of equipment but at quite an early stage an atmospheric combustion rig was installed, the air for combustion being supplied by a "Jumo" compressor driven by a 100 h.p. variable speed motor. Equipment was installed for measuring air flows, temperatures and pressures throughout the system. Many types of simple combustion chambers were tried and it soon became apparent that complete and rapid combustion could best be obtained by pre-heating the mixture of air and fuel as it entered the chamber.

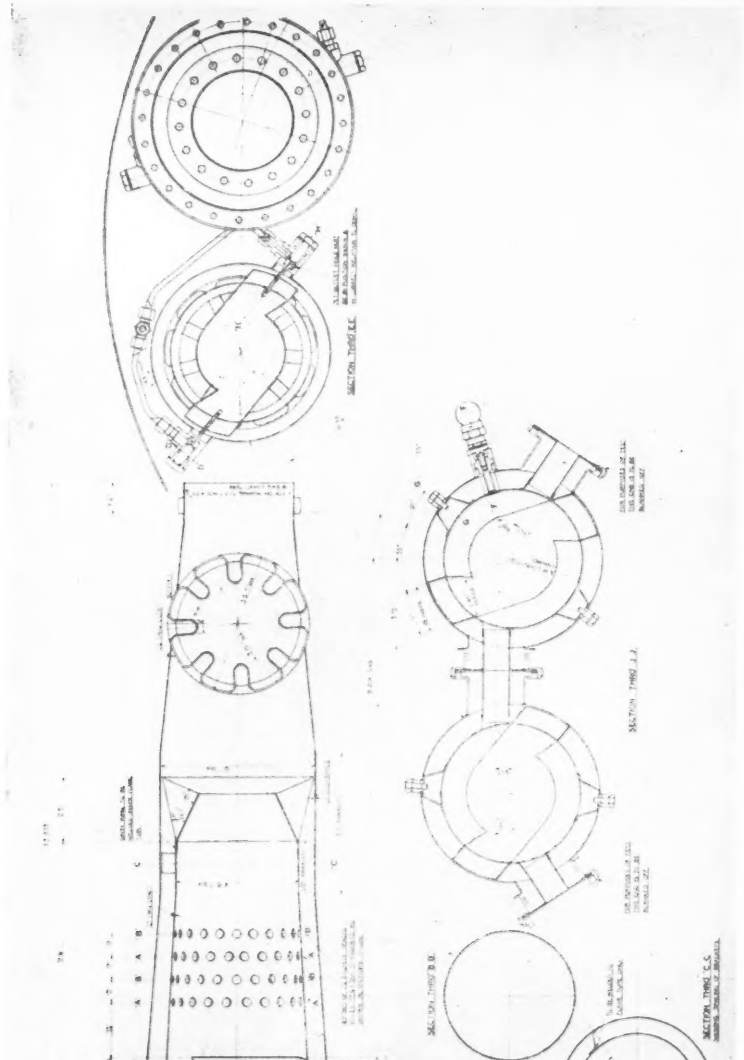
Originally this scheme was carried out by arranging for a small pilot burner in the nose of the chamber which directed its products of combustion on to the main mixing chamber. The main features of this combustion are shown quite clearly in Fig. 17. This chamber worked satisfactorily on the rig but was complicated and would prove difficult to install and to control on an engine, but it was from this chamber that the first actual engine unit originated. The great simplification that was performed was made possible by the realisation that the products of combustion from the main burner itself could be used for heating the burner by the simple expedient of allowing the gases to escape from the burner in an upstream, rather than in a downstream, direction.

The first chamber incorporating this new idea was the prototype chamber for the A.S.X. engine and is shown in Fig. 18. This chamber worked very well indeed on the rig and the exact form of the pre-heater type of mixer is clearly shown. Air was admitted to the mixing chamber in a tangential direction from two forward facing ducts in the annulus between the flame tube and the combustion outer casing. At the point at which the air stream entered the mixing chamber, fuel was dribbled into both air intakes by means of two jets. The swirl caused by the tangential entry of the air into the chamber flung the heavy particles of fuel against the mixing chamber walls where it was vaporised, as the walls were kept hot by the products of combustion. A mixture of finely divided fuel, fuel vapour and air emerged into a forward part of the flame tube, the products of combustion thus flowing over the mixing chamber and heating it.



Combustion chamber (Lindall pre-heater type).

Fig. 17.
Original vaporising chamber.



Combustion chamber (self pre-heater type).

Particulars of Spring

| | | | | | |
|---|---|---|---|---|---|
| No. of coils | ... | 4 | Rate | ... | 547 lb./in. |
| Dia. of Wire | ... | 14 SWG (.08 in.) | Free length | ... | 1.025 in. |
| Mean dia. | ... | 3 in. | Fitted length | ... | .925 in. |

Fig. 18.

First A.S.X. combustion chamber.

In order to enable the chamber to work satisfactorily over a wide range of mixture strengths, secondary air was admitted into the forward part of the chamber by means of louvres pressed into the nose piece. Under conditions of weak mixture the mixture at exit from the mixing chamber is such as to allow complete combustion, but at the rich end of the range there is a shortage of oxygen and this deficiency is made up by the extra fresh air admitted from the louvres. At the plane immediately behind the mixing chamber, combustion is about 80 per cent. complete and the tertiary air admitted through the holes in the after end of the flame tube provide the necessary oxygen for completion of combustion.

At the end of the flame tube it is necessary to mix the hot gases issuing from the flame tube with the relatively cold air flowing in the annulus. After many different types of mixers had been tried, the best mixing was found to be effected by means of four simple scoops fixed to the outer casing of the chamber at the exit from the flame tube. The scoops themselves are in the cold air stream surrounding the flame tube and they deflect this cold air into the centre of the chamber. The low pressure region behind the scoops serves to deflect the hot gas outwards, thus starting the mixing process which is practically complete by the time the gases reach the chamber exit.

Fig. 18. First A.S.X. combustion chamber.

This then was the first chamber tried on the A.S.X. engine. After working quite successfully on the test rig the early history on the engine was most disappointing and it was obvious from inspection that combustion was occurring outside the flame tube, with consequent damage to the outer casing. This trouble was quickly traced to the instability of the two forward facing air ducts leading into the mixing chamber. If the air flow from the compressor was in any way uneven, or if the flame tube was not properly centralised, air would flow into one of the ducts, mix with the fuel and then emerge from the other duct and the fuel or mixture would ignite and burn outside the flame tube.

This was a serious condition and numerous attempts were made to prevent it, but eventually it became apparent that the only way to guarantee that this would not happen was to design a mixing chamber which had only one entry, instead of two. This was done and completely cured the trouble, but it was only done at the expense of a slight lack of symmetry on the part of the mixture issuing from the mixing chamber into the combustion chamber, which is still a feature of this combustion chamber.

Except for minor constructional alterations to this design, it has remained unchanged and behaves satisfactorily. In the early days the only way of discovering how long a chamber would last was to run it on the engine, which meant that experience was gained slowly. In 1945 a set of equipment was installed so that chambers could be tested on a rig under conditions of temperature and pressure exactly equivalent to those obtained on the engine. Air is supplied from three Browett Lindley air compressors, each capable of delivering just over 2 lb. of air per second, thus giving an air supply of about 6½ lb. per second.

This air can supply either one or both of two pressure rigs which are complete with water-cooled throttle valves and pressure and temperature plotting apparatus and have proved of inestimable value in the mechanical development of the combustion chamber. Long endurance runs have been made on this type of chamber on this rig and Fig. 19 shows a dismantled combustion chamber assembly after completing 300 hours running under type test conditions on the pressure rig. The running was done in the same cyclical periods as for the main engine and no maintenance whatever was done on the chamber during the run.

Apart from behaving under conditions of high temperature and pressure at sea-level conditions, it is also essential that a combustion chamber operates equally well under conditions of higher altitudes, where the density and temperature is rather low and the fuel consumed is small. Conditions are particularly bad when the engine is slow-running, as the pressure and temperature rise in the compressor is then very small and the fuel required is a minimum. The first experience of the behaviour of this vaporising type of chamber under altitude conditions was obtained in the initial flight trial of the A.S.X. engine. The results of these trials were most encouraging as it was found to be possible to perform all the operations of slow running and re-starting at altitudes up to 35,000 ft., which was the ceiling of the Lancaster machine with this installation.

The combustion problem for the Mamba was more difficult as, unlike the A.S.X. engine, the length available for combustion and mixing was restricted. Means had to be found for the processes of pre-heating,

vaporisation, combustion and mixing in a short length, which meant that some of the processes would have to go on simultaneously, rather than one after another as in the case of the A.S.X. chamber.

Work on rigs started at the same time as the main engine but many hundreds of experiments had to be made before even a reasonable chamber resulted. Finally, a satisfactory solution to the difficulties was found and Fig. 20 shows the Mamba vaporising type of combustion chamber. Superficially it is completely different from the A.S.X., but, in fact, the principles involved are identical. The vaporisation of the fuel in contact with air is carried out in four tubes bent into a walking-stick shape and the secondary air is fed in by means of four units resembling over-sized Bray-type gas jets. These air jets introduce air into the chamber in four radially disposed sheets which divide the flame tube into four segments, the exit from each of the walking-stick tubes being in the centre of these four segments. By this means all the air required for combustion over the whole of the operating range of the chamber is provided and combustion is completed in a very short space.

In order to keep external walls cool, the mixing arrangements had to be altered. This mixing process is one in which fundamental knowledge is still lacking and success is achieved by a method of trial and error. The resulting mixer was quite simple and consisted of four rectangular holes in the tapered mixing section which are crossed from end to end by a flat spoiler strip. The purpose of these spoiler strips is to regulate the degree of penetration of the cold air streams into the core and thus to achieve a uniform outlet temperature.

The chamber as shown has behaved very well on the engine and it was a chamber of this type which was incorporated in the

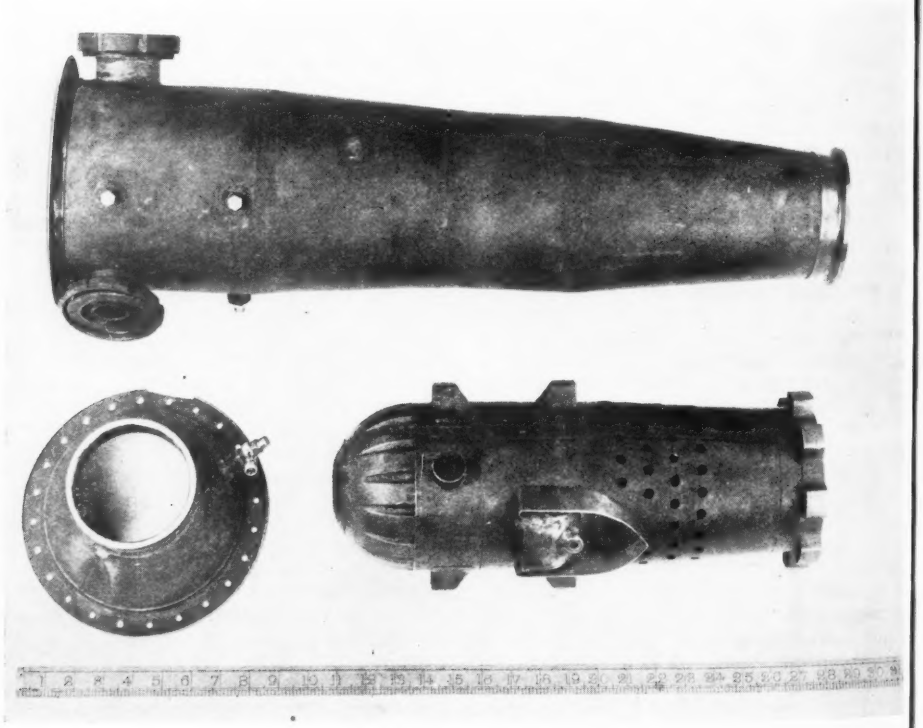


Fig. 19.
Combustion chamber after 300 hour test.

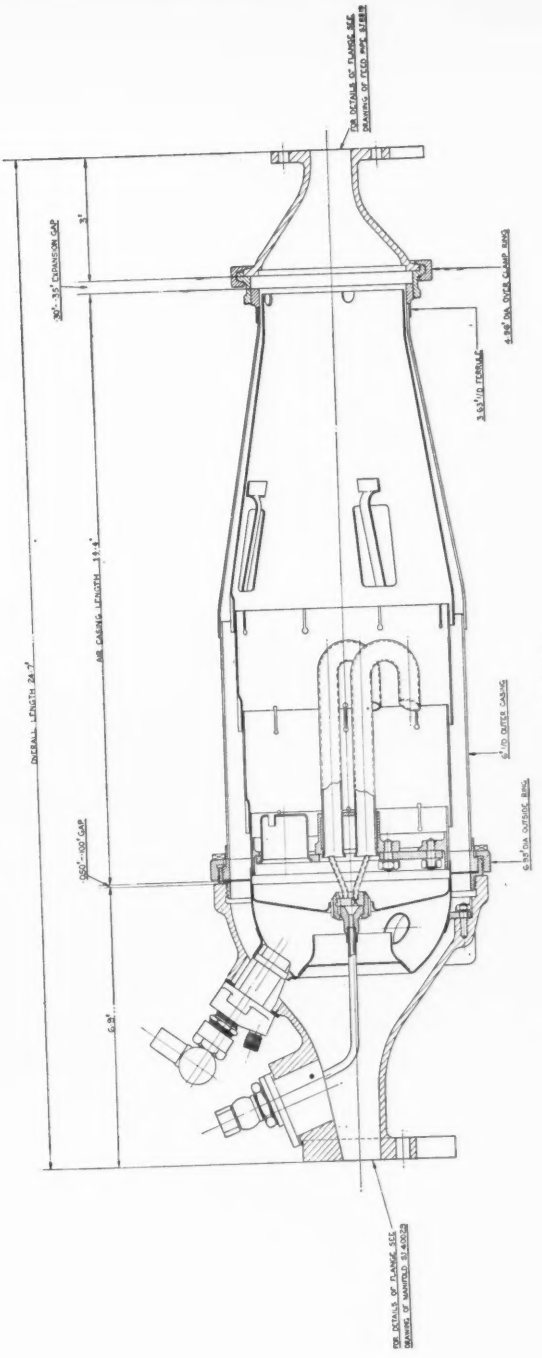

FOR DETAILS OF FLANGE SEE DRAWING OF FEED PIPE S1/8838
3"
30"-35" EXPANSION GAP
4.98" DIA. OVER CAMP. RING
3.63"/10 FERRULE
DETAIL LENGTH 24.7"
AIR CASING LENGTH 19.4"
6.10" DIA. OUTER CASING
6.39" DIA. OUTSIDE RING
900"-1007 GAP
6.8"
FOR DETAILS OF FLANGE SEE DRAWING OF MANIFOLD S1/8838

Fig. 20.
Mamba combustion chamber.

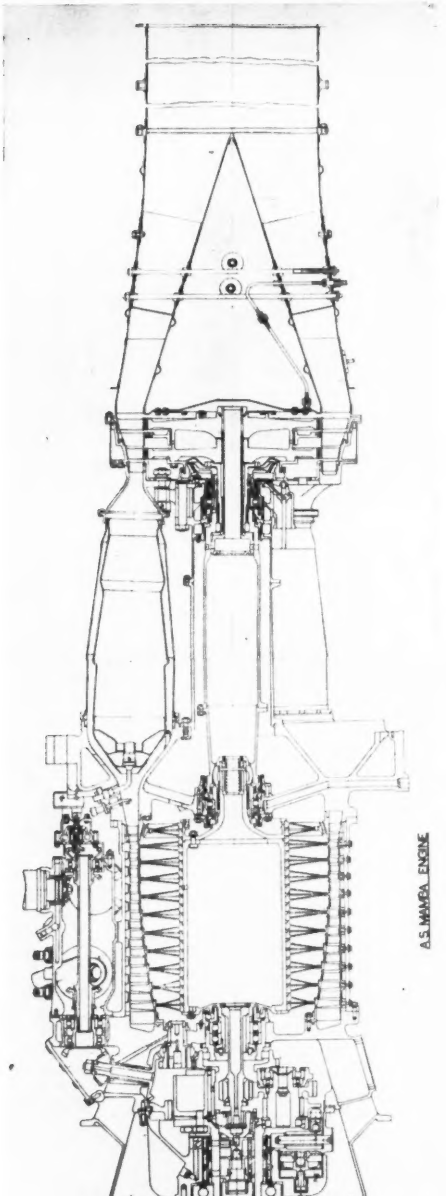



Fig. 21.
General arrangement of Mamba engine.

engine which did a successful type test. In view of its success it is now the standard chamber for all future Mamba engines.

Work is being actively pursued on further developments of vaporising combustion as, in our opinion, it has certain outstanding advantages which it might be useful to summarise. The advantages that are claimed for it are as follows:—

1. Combustion in the vapour phase is easier to control and can be arranged to proceed to completion under widely varying conditions of inlet temperature and pressure.
2. The use of specialised atomising jets with their accompanying troubles of penetration and patternation is avoided.
3. Because of the lack of a high pressure spray jet, the maximum fuel pressures used need only be those necessary to operate the various fuel servo devices in the engine fuel system and need not exceed 400 lb./A in. This feature is of major importance in obtaining fuel pump reliability.

Figure 21 shows the general arrangement of the Mamba as developed, and a comparison of this and the original design, as shown in Fig. 2, is interesting.

## CONTROLS

The development of the gas turbine propeller engine from the simple pure jet engine introduces a new independent variable into the control system. In the simple jet engine with fixed propelling nozzle the rotational speed of the engine is determined by the amount of fuel supplied and this alone has to be controlled. When power is delivered to a variable pitch propeller the rotational speed of the engine can be varied for a constant fuel flow by altering the pitch of the propeller and hence, the power it is capable of absorbing at a given rotational speed.

The introduction of this new variable increases the number of possible control systems considerably and a somewhat arbitrary decision needs to be taken as to which system to develop. For the Mamba it was decided to use a similar type of fuel control to that used on a jet engine and to retain the normal piston engine type of constant speed unit for controlling the engine speed. This system seemed to be at least as good as any other and to have the great advantage that its components were already developed to a large degree and hence, the development work could be confined to their satisfactory inter-connection, so that finally the pilot could control the engine by the movement of a single lever.

Figure 22 shows diagrammatically the arrangement of the fuel control unit and the pump. Both these items are supplied by Joseph Lucas Limited, to whom thanks are due for permission to use the diagram. The fuel control unit appears at the bottom of the picture and it can be seen that the half ball valve "A" controls leakage from the servo system of the pump. Increasing the leakage from this valve reduces the pump stroke and hence the fuel flow at a given speed and similarly, reducing the leakage increases the flow.

The position of the valve is controlled by a lever in equilibrium between forces supplied by capsules "B," the upper capsule being in communication with the atmosphere and the lower capsule being evacuated, and a piston "C" operated by the differential pressure across the control orifice "D." By this device the pressure drop across the control orifice depends only on atmospheric pressure and is reduced as the atmospheric pressure is reduced. The effective size of this orifice is controlled by the pilot's throttle valve "E" and as the pilot opens the throttle the orifice and hence the fuel flow, increases. This provides a system by which the fuel flow can be varied from slow running to full throttle with automatic reduction in flow over the whole throttle range as the altitude is increased.

The law relating fuel flow to altitude, of course, is fixed by the geometry of the control and is arranged to be correct for standard I.C.A.N. conditions. Any departure from these conditions calls for separate adjustment, which will be discussed later.

The control of fuel has to be related for a gas turbine propeller engine to the speed at which the engine rotates. For a pure jet engine with a fixed nozzle, there is a fixed connection between the amount of fuel and the rotational speed of the engine, but with a gas turbine engine with a variable pitch propeller there is no such automatic connection.

Figure 23 shows the relationship between the shaft horse power and r.p.m. for different fuel flows for the Mamba engine. It can be seen that, generally speaking, the shaft horse power produced is independent of the r.p.m. over a short range but that there are strict

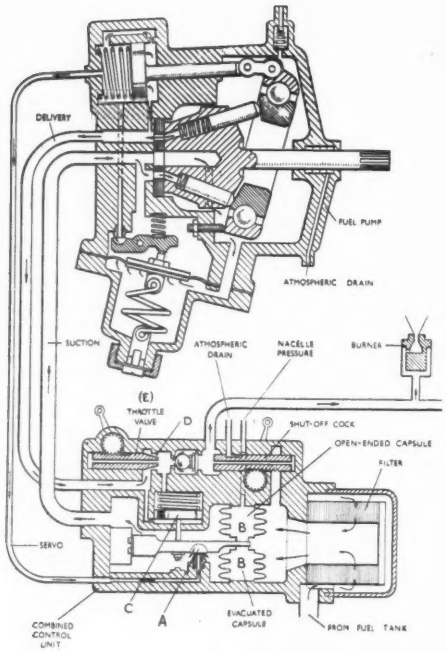



Fig. 22.
Lucas fuel control system.

limitations to this statement, as overheating of the turbine and surging of the compressor have both to be avoided. Fig. 23 shows this limitation on performance and also shows curves of power absorbed by the propeller for different propeller pitch settings. It can be seen that as the speed of the engine drops from 15,000 r.p.m. to 8,000 r.p.m. the propeller pitch which can be used with safety, decreases from 23° to 12°. It is this need to have the propeller at 12° pitch when idling which introduces the main new factor in the propeller controls of gas turbine engines.

Another feature of the engine performance which is of importance in this connection is the fact that the specific fuel consumption of the engine remains the same at the same shaft horse power output, even when the speed of the engine is altered over a small range. In other words, without losing economy, it is possible to work at more than one condition of speed and jet pipe temperature for a given power output. This important fact makes it possible to choose an arbitrary relationship between r.p.m. and fuel flow controlling the engine without sacrifice of economy, always provided that the limits of operation shown in Fig. 23 are not exceeded.

Propeller control, therefore, is effected by means of linking the fuel control mechanically to the c.s.u. control in such a way as to make the engine operate on an arbitrary chosen line, which will give reasonable alterations in speed and jet pipe temperatures for the various engine ratings from minimum cruise to take-off power.

This rigid connection between speed and fuel will allow the engine to operate safely and successfully at any speed within its running range, provided conditions are steady. A successful aero-engine has to be able to accelerate and decelerate very rapidly, and under these conditions significant departures from the chosen operating line occur. The reason for this is not difficult to see if we consider the case of a rapid acceleration. The pilot opens the throttle say, from minimum cruise to take-off position and by this motion of his lever does two things. First, he increases the fuel supply to the engine from that selected for minimum cruise to that needed at take-off, while the engine is running at constant speed; and secondly, he selects a higher speed for engine rotation by altering the c.s.u. setting.

If the amount of fuel added is great enough, the engine will surge but it is not difficult to avoid this. The selection of higher rotational speed for the propeller would immediately cause the c.s.u. to tend to reduce the propeller pitch and the engine would accelerate rapidly up to full speed with the propeller absorbing less power. This would obviously cause a considerable overshoot in speed which would automatically be corrected by the engine's over-speed governor cutting the fuel off again, but in this case the maximum power will not be available. To prevent this occurring a hydraulic delay mechanism is incorporated in the linkage between the fuel control unit and the constant speed unit which delays the alteration to the c.s.u. setting when the pilot opens the throttle rapidly.

The hydraulic delay unit is rather complicated but its effect is to ensure that during an acceleration the speed selected by the c.s.u. is always slightly less than the instantaneous speed of the engine. This ensures a steady increase in pitch of the propeller during the acceleration, and the timing is so arranged that when full speed is reached by the engine,

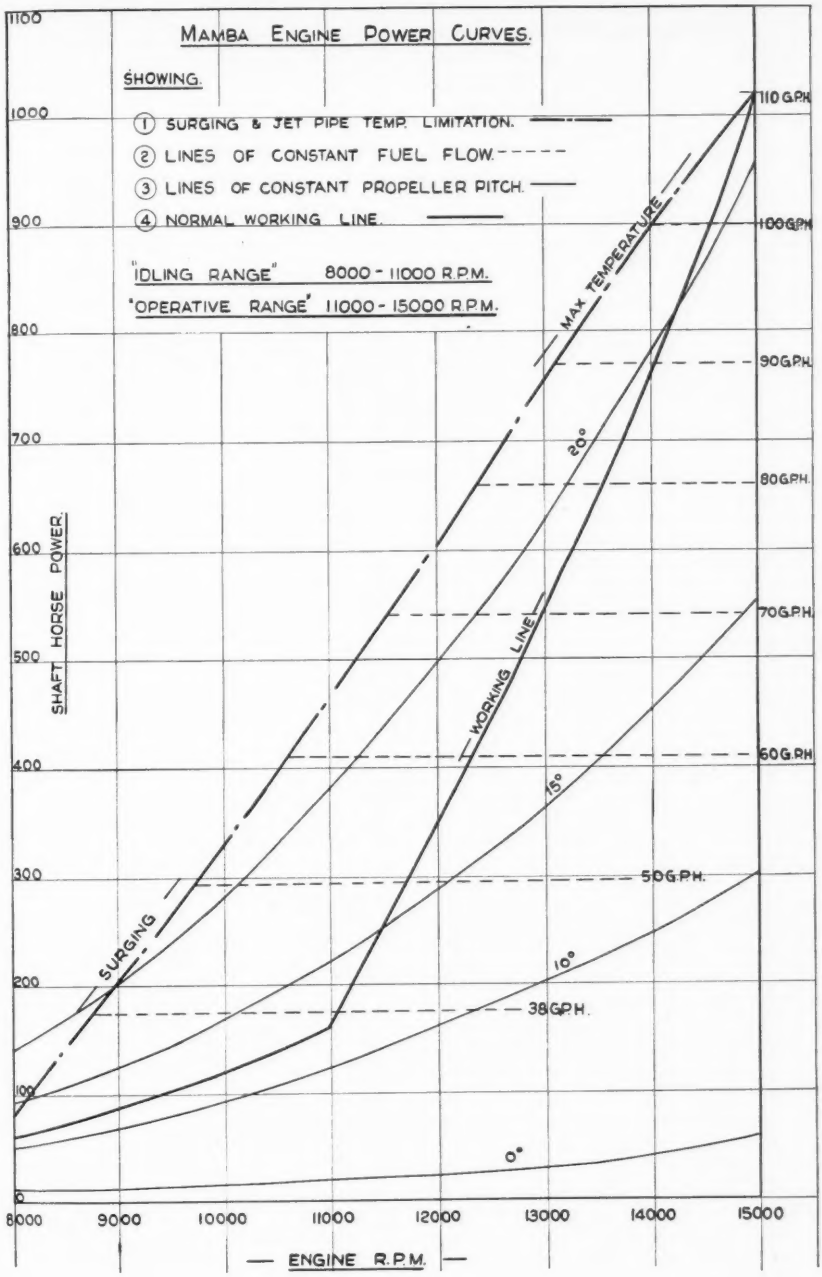



Fig. 23.
Mamba power curves.

the propeller is in the correct pitch to absorb the take-off horse power.

The controls discussed so far arrange for the engine to be operated successfully both in handling and under steady running conditions at any speed and altitude, providing the atmospheric temperature does not deviate sensibly from standard. Gas turbine engines are very sensitive in their performance to changes in intake temperature and if the maximum power available is to be obtained at any instance without overheating the turbine blades, it is essential to make allowances in the fuel system for variations in atmospheric temperature. The power available from a gas turbine engine of this type decreases roughly by ¾ per cent. for every 1°C. rise in intake temperature and this increase or decrease in engine power has to be catered for by the fuel system in providing more or less fuel as the temperature varies.

This variation can be provided in a number of ways, the most obvious being the control of fuel directly by some device sensitive to atmospheric temperature. Unfortunately, in practice, such a device proves complicated and can be unreliable and as the whole safety of the engine depends upon avoiding over-heating the turbine, any unreliability cannot be tolerated.

The method chosen for temperature adjustment is an apparently indirect one. As was stated earlier, alterations in intake temperature affect all the temperatures of the cycle, including the jet pipe temperature, and as this latter most nearly approaches the turbine operating temperature and is readily measurable, this has been chosen for the control.

The system works by allowing the main fuel control unit to supply enough fuel to operate the engine, at the maximum power the engine is allowed to produce when it is under conditions of subnormal air intake temperature. A bleed valve is arranged on the pressure side of the fuel system and can bleed fuel directly back to the intake side of the pump. It is operated by an electric motor which is controlled directly by the signal received from thermocouples in the jet pipe, operating through an amplifying device. The jet pipe temperatures, which correspond to the various powers in the operating range of the engine under I.C.A.N. conditions, are selected by the appropriate pilot's lever position. Since, under any conditions except those of the lowest air intake temperature, the jet pipe temperatures produced by the fuel flow selected by the main fuel control unit will be higher than these, the thermocouple relays will open the spill valve and thus reduce the amount of fuel entering the combustion chambers, bringing the jet pipe temperature to its correct value.

Such jet pipe temperature controls can be made to work quite well and when they are used in this fashion the fact that they work inherently slowly does not matter, as the whole of the control of the engine under accelerating or decelerating conditions is independent of their action.

Another advantage of this method of operation is that a failure of this device will not prevent the engine functioning but will merely mean that the pilot will have to adjust the jet pipe temperature by means of moving the throttle in the case of failure, which will only mean a slight reduction of the available power.

So far only the operation of the engine under various conditions has been considered from a test bed point of view. The complete system will operate just as successfully in flight, but special precautions have to be taken because of the ability of the propeller to fine off right down to 12° pitch. This can cause serious trouble in flight in the event of an engine failure.

With a conventional piston engine, which has fine pitch stops on the propeller set at some 25°, if the engine fails it will windmill on its fine pitch stop until such time as the pilot can operate the feathering device. During this windmilling time the position of the fine pitch stop is such that no abnormal drag is experienced by the aircraft. With the very much finer stop setting required by the Mamba, however, the drag of the propeller windmilling on the stop can be very serious indeed and might cause a complete loss of flying control on the part of the pilot.

The solution to this difficulty is the provision of a "reverse torque switch" on the engine reduction gear. This is a switch which is operated whenever power is fed into the engine from the propeller, as in the case of an engine failure, and because of its operation over-rides the c.s.u. and brings the feathering device into operation. Thus, instead of fining off, the propeller will coarsen up to its feathering position with a minimum of drag on the aircraft.

The system as described will cater adequately for all normal operations of the engine and an engine failure in flight will cause no additional trouble other than the

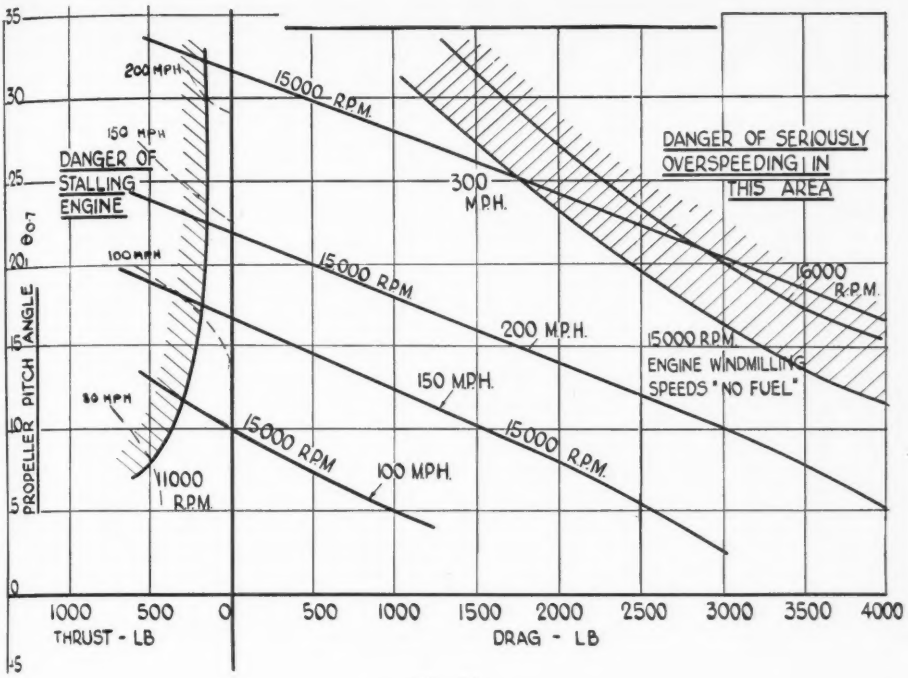



Fig. 24.

Propeller drag and thrust curves.

loss of engine power. Another possible type of failure which must be considered is a failure of the constant speed unit controlling the propeller, either because of an oil system failure or mechanical fault in the unit itself.

If the c.s.u. fails in flight the pitch of the propeller is uncontrolled, but because of the shape of the propeller blades centrifugal forces always tend to make propeller blades move towards the fine position. Thus after a c.s.u. failure in flight the propeller will reduce its pitch to 12° and will no longer absorb the engine power. The engine speed therefore will increase until it is restricted by the overspeed governor, which will reduce the fuel supply down to zero if necessary.

Figure 24 shows the effect of an engine running under these conditions. It can be seen that the 12° pitch setting will just allow no drag at 110 miles per hour, which at least makes the aircraft safe at low speeds so that an approach and landing can be made. At higher speeds severe drag is caused and above 270 m.p.h. the windmilling torque on the engine is great enough to overspeed the engine to a dangerous extent, despite the fact that the overspeed governor has now cut off all the fuel. Fig. 24 also shows that little or no relief can be obtained by the pilot cutting his engine, as the drag figures for "engine off" are still serious.

Some extra device therefore must be built into the propeller control mechanism to act as a safety device under these conditions and this device must not interfere with the normal operation of the propeller, which is already satisfactory.

Such a device has not yet been provided but at least a partial solution has been found. This is a removable fine pitch stop which automatically comes in whenever the propeller is coarse enough, but which can be removed either by the pilot or by interlocking it with some other control. The function of this stop can best be explained by an example.

Referring again to Fig. 24 we can see that a stop set at 28° would prevent engine overspeeding and reduce satisfactorily the drag after a c.s.u. failure. In normal flight the stop would be in whenever the propeller setting as determined by the c.s.u. was coarser than 28°. This, in fact, would occur under all cruising conditions above 200 m.p.h. A c.s.u. failure then in normal flight would result in the propeller operating in fixed pitch at 28°, which would give enough thrust to get the aeroplane back to base. Fig. 24 shows also that if the stop were left in, the engine would be overloaded at any speed less than 180 m.p.h. and, when throttled back, would overheat and stall.

The pilot must remember therefore to remove the stop every time he reduces speed below this value in normal flight if he is to avoid trouble. Hence, from a normal operational point of view, his control system is less satisfactory than before.

If the removable stop could be reduced in pitch to 23° he would get less protection in case of a c.s.u. failure, but he would not have to remove the stop until speed had been reduced to 140 m.p.h., at which point he would normally select flaps down. Thus the stop removal could be connected to the flap operation and would be carried out automatically. This, at the best, is a compromise, but one which will probably be used for the time being.

In the meantime other methods are being actively pursued and undoubtedly a solution will be found which will satisfy all requirements.

## STARTING

One of the problems associated with the gas turbine propeller engine is that of starting. All engines of this type, whether pure jets or gas turbine propeller-engines, have a minimum speed below which they cannot run under their own power and it is essential, in order to achieve a start, to accelerate them by some external means up to this speed.

During the period in which external power is provided, this power has to be used in two ways: firstly, in accelerating the propeller and turbine up to the starting speed, and secondly in pumping air through the engine during the acceleration. The energy needed to accelerate the rotating masses up to the starting speed is constant and independent of the time interval during which the starting motor is in engagement, but the energy put into pumping air depends upon the time for the start. Fortunately, it is possible by attention to the fuel system to make sure that the combustion chambers are lit almost as soon as the engine begins to rotate and this reduces considerably the pumping energy required, as the higher temperature at the turbine inlet allows the turbine to produce almost enough power to drive the compressor.

By attention to the engine itself, therefore, it is possible to reduce the energy required for a start almost to that required to overcome the interia of the rotating parts alone and it is found that the total energy input to achieve a start is almost independent of the time during which the starting motor is in engagement. In other words, doubling the power of a starter motor will halve the starting time and a start will be achieved with approximately the same energy input.

It is possible therefore to choose within limits the time for a start. This is bounded on one side by the torque-carrying capacity of the starter drive and on the other side by the fact that during a start the turbine runs much hotter than normal and it is essential to limit the period in which the turbine blades are subjected to high temperature to a few seconds.

It is not necessary in the gas turbine propeller-engine to achieve the very rapid starts which are a requirement for jet engines to be used in fighter aircraft and it has been found that a reasonable period for the starting process is about 20 seconds. The Mamba engine requires an eight brake-horse-power motor to achieve a start in 20 secs., and this is the size of motor which is being provided.

Three types of starter motor have been considered for the Mamba engine.

1. Electric motor.
2. Turbine motor.
3. Displacement motor driven by cartridge gases and compressed air.

Of these three the turbine starter has not progressed very far because of the lack of need for a very quick start for which this starter is particularly suitable.

The other two types have been developed and the electric starter has been standardised.

The original starter for the engine was of the third type and was designed and developed by Armstrong Siddeley Motors Ltd. This starter is essentially a reversed vane pump and its main features are shown in Fig. 25. It can be run on compressed air or on the gases produced by cartridges.

When provided with this starter the engine can be started either from a compressed air line or from high pressure air bottles through suitable reducing valves, or from chemical cartridges, one suitable type of which is ammonium nitrate, a cartridge developed by I.C.I.

Since the energy input to this starter depends only upon the product of pressure and volume of the gas supplied to the starter, it is obvious that the weight of charge required to achieve a start will vary inversely with the temperature of the gases. Because of the construction of the starter there is a distinct upper limit to this temperature and hence, the charge weight cannot be reduced below a given size, which in the case of the Mamba is about 3½ lb.

For bench testing and for all the initial flight work, this starter has been used operating on compressed air, either from a normal works supply or from high pressure air bottles in conjunction with suitable reducing valves. This system has proved ideal for experimental work as, provided that compressed air is available, the starter motor can be used for long periods—as is often necessary during investigation work on the test bed.

For ultimate aircraft use however, the electric starter has distinct advantages as it can use existing aircraft facilities and, for the Mamba the current required is not prohibitive.

It is anticipated therefore that electric starting will be used in the production phase of the engine.

## INSTALLATION

In general it can be stated that the problems involved in installing the gas turbine propeller-engine in an airframe are similar to, but somewhat simpler than, the corresponding problem of installing piston engines. Because of the smooth running of the engine it seems that it will be possible to dispense with flexible mounting. Also, the lack of external cooling needed for the engine makes the installation more simple. Fire walls must be provided to separate the "cold portions" of the engine from the "hot portions" and precautions must be taken to avoid failures caused by oil pipes and services causing fuel or oil to come into contact with "hot portions" of the engine. Fire extinguisher rings must be provided in the "hot portions" of the engine to deal with any fires which may accidentally occur because of failures of any of the hot gas casings.

In the smaller power class, because of the very much reduced physical size of the engine, compared with the piston engine, the accessories become a very real problem. The Mamba engine completely cowled is only some 30 in. in diameter and the nacelle has to be faired into the wing and must house not only the engine accessories, but all the aircraft accessories as well. For a civil installation, the housing of such things as cabin blowers and large generators in such a small space is extremely difficult.

Because of the low oil consumption of a turbine engine the amount of oil that has to be carried for a flight is small. This makes possible the incorporation of the complete oil system, including oil tanks, in the power plant itself, despite its small size, thus allowing easy engine changing and maintenance.

A feature which these engines share with jet engines is the large amount of air they inhale during flight. With a jet engine it is fairly easy for the air intakes to be of high efficiency, but with a propeller engine this is a more difficult problem. If the full benefit of the gas turbine engine at high speed is to be achieved, it is absolutely essential that air intakes are provided which cause the minimum possible loss.

The Mamba engine is a "straight-through" engine in which the air intake diameter is very small and air must be taken round the propeller spinner and past the propeller blade roots themselves. With a conventional spinner there is little doubt that considerable loss will be caused by the presence of the somewhat crude blade roots. Flight tests show that this loss is as high as 12-15 per cent. of the free stream dynamic head.

One way out of this difficulty is the design of a ducted spinner. In this type of spinner the outer cowl of the engine is brought forward over the propeller blades, thus forming an annulus within which the round portions of the blade are faired in with rotating streamline cuffs set at the correct incidence angle. Aerodynamically there is little difficulty in designing such a spinner, but the mechanical probems involved are difficult. If engine efficiency at flight speeds greater than 300 m.p.h. is to be maintained with gas turbine propeler-engines of this type, there is little doubt that ducted spinners will have to be developed and used.

The problem which is exercising the minds of aircraft constructors and operators is that

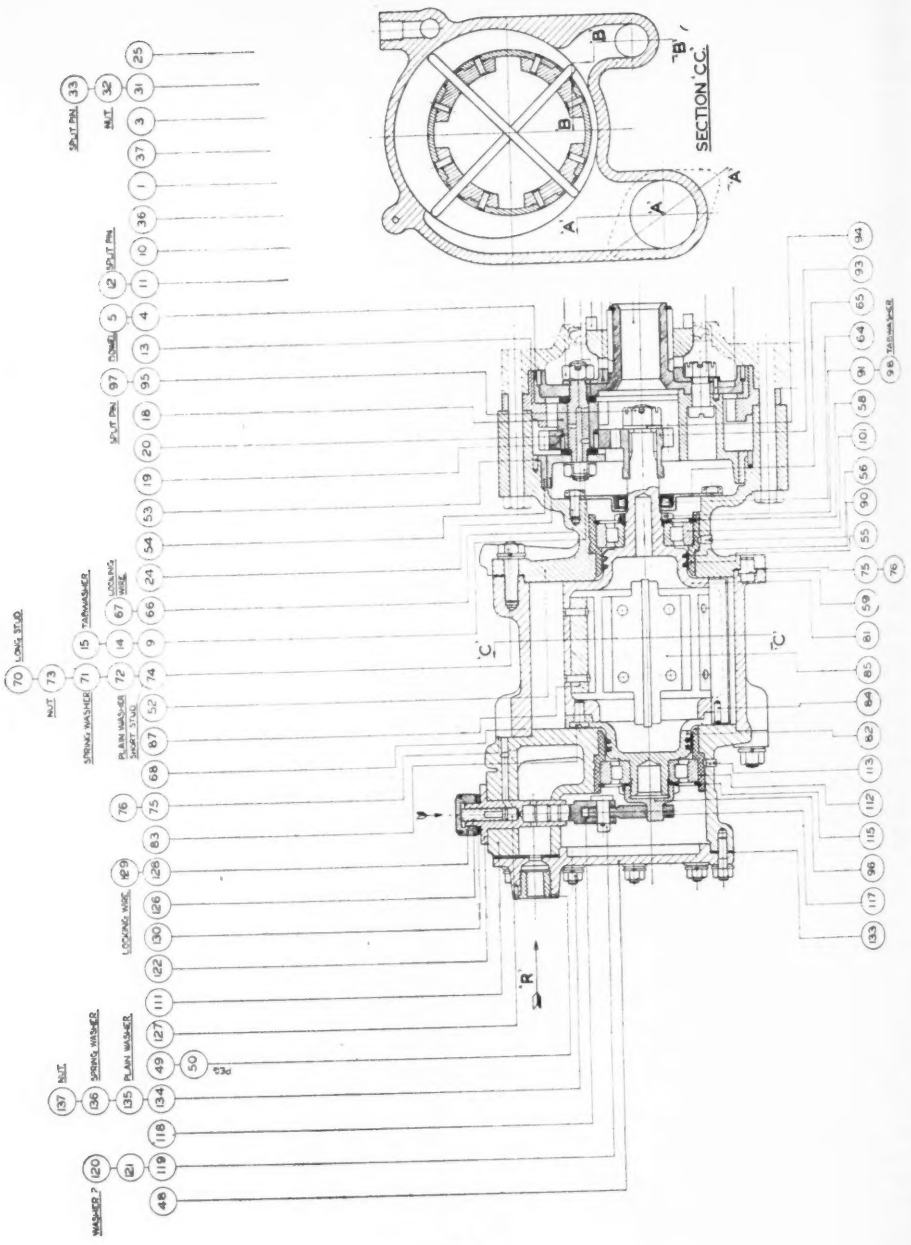



Fig. 25.
Mamba gas starter motor.

of de-icing. It has been thought for some time now that the de-icing of gas turbine engines woud prove a difficult problem, especially in the axial flow type of engine, because a large particle of ice breaking off and going through the engine would cause considerable damage to compressor blades. The dependence of the engine upon a good air intake and the large quantities of air involved will also add to the difficulties which would occur when flying under icy conditions.

Fortunately, the gas turbine engine is one in which there are large quantities of heat available for de-icing purposes, and if attention is directed towards anti-icing rather than de-icing, there seems to be little doubt that gas turbine propeller-engines can be made suitable for flying under severe icing conditions with perfect safety and with little loss in power. This can be done by arranging for hot gases to be injected automatically into the air intake whenever icing conditions occur, thus ensuring that any air which scrubs unheated surfaces, such as guide vanes, is raised in temperature above the freezing point of water before reaching these surfaces. The main surfaces of the air intake themselves will always be kept warm enough to ensure that no ice can form on them in any circumstances.

The disposal of the exhaust gases from a gas turbine engine becomes a problem to aircraft designers generally, as the diameter of the jet pipes is usually embarrassingly large. In this respect the gas turbine propeller-engine is better than the jet engine however, for although the exhaust area required is somewhat larger, the energy of the gases is less and it is possible to take more liberties with the disposal of the gases than is possible with the pure jet engine.

Thus, the jet pipe of the gas turbine propeller-engine need not be straight and can emerge from the fuselage at quite considerable angles to the fore and aft position. The jet pipe can also, if necessary, be bifurcated in order to produce a jet on either side of a machine. This gives the aeroplane designer much more latitude in the disposal of the exhaust gases and this fact should be taken into account on any installation of a gas turbine propeller-engine.

Mamba installations have now been developed for four aircraft, in addition to the original flying test bed installation in the nose of the Lancaster engine which is shown in Fig. 27. These four aircraft are:—

1. The Boulton Paul Balliol Trainer.
2. The Avro Athena Trainer.
3. The Miles Marathon Civil Aircraft.
4. The Apollo Aircraft.

The first two are fuselage nose installations and because of this there is ample space available for services and accessories and I do not intend to describe them in detail.

The Apollo installation has been worked out to occupy the minimum space and diameter consistent with ease of access and maintenance and is worth a more detailed explanation.

### The Apollo Power Plant

Figure 26 shows the arrangement of the Mamba power plant designed for use in the Armstrong Whitworth Apollo aircraft.

As can be seen, the power plant is a completely self-contained unit and fits into a cowling having a maximum diameter of 31 inches.

The power pant is divided into three zones by stainless steel fume and fireproof bulkheads.

*Zone* 1. *The Compressor Zone.*

This contains all engine accessories, including fuel pumps, oil pumps, constant speed unit, feathering pump, oil tank and cooler. It is ventilated and the air temperature inside this zone will not exceed 50°C.

*Zone* 2. *The Combustion Chamber Zone.*

As its name indicates, this zone includes the six combustion chambers, the turbine feed manifold and the turbine itself. The chambers are covered with a light stainless steel cylindrical shield which matches up at the turbine end with the outer cowling and the annular space between this shield and the outer cowling is ventilated to keep the temperature down to 100°C. All pipes and electrical services to Zone 1 pass through this annular space and are adequately protected. The electric leads to the feathering pump are fed through a separately ventilated exit.

*Zone* 3. *The Jet Pipe Compartment.*

This compartment aft of the turbine, houses the exhaust cone and tail pipe and in addition, the ignition booster coils and the aircraft accessory boxes. The compartment merges into the wing structure and the temperatures in the compartment are expected to be low.

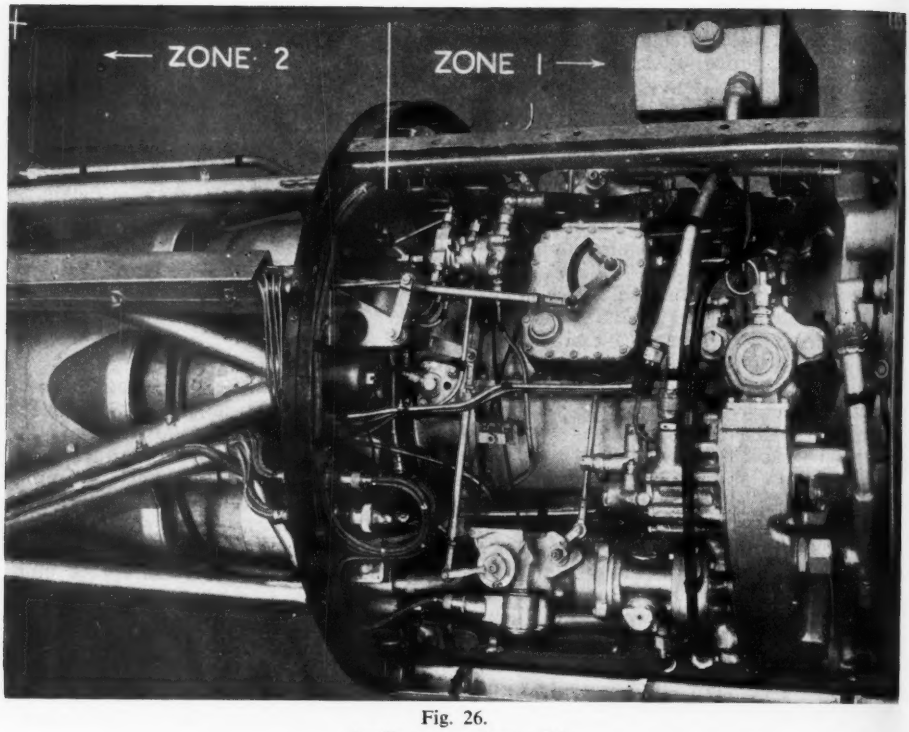



Fig. 26.
Apollo power plant. (A).

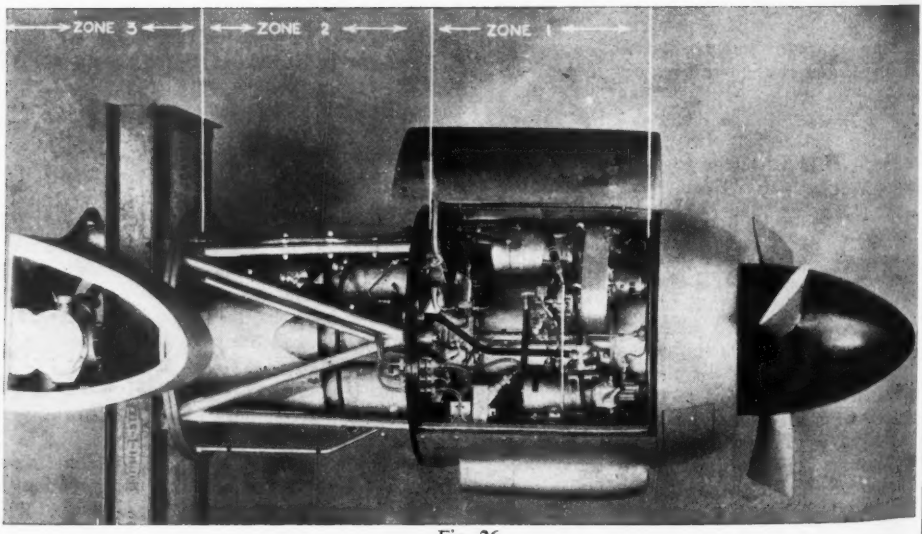



Fig. 26.
Apollo power plant. (B).

Fig. 27.
Mamba Lancaster.

Weight and space have been saved by making the nose cowl immediately aft of the propeller blades an oil tank, in which spot welded construction has been used to eliminate the possibility of compressor damage caused by the ingress of broken rivets into the compressor. The whole of the oil system, which caters for a flow of 500 galls./hr., is in Zone 1. Oil temperatures are automatically controlled by an electrically-actuated flap governed by a thermostat and "Desyn" transmitters are fitted to give visual flap indication to the pilot. The engine mounting is of welded tube construction for lightness and, although of rigid design, some work is now being done on rubber mountings.

Two controls only are provided, one for throttle control and the other for operation of the isolator valve which is inter-connected mechanically with the over-ride lever for mechanical feathering. The controls are housed in light gauge steel tubes through Zone 2.

A drive from the engine accessories casing is taken from the engine through Zones 1 and 2 to a bevel box above the exhaust cone jet pipe joint. The drive is then bifurcated and taken downwards and outwards at 45° to subsidiary boxes on which are fitted cabin blowers, generators and hydraulic pumps.

A three-bladed 10 ft. diameter de Havilland hydromatic propeller is fitted. This has dural blades fitted, for two-thirds of their length, with electric de-icing overshoes, which are energised by means of a hub

Fig. 28.
Boulton Paul Balliol Mk. 1 aircraft.

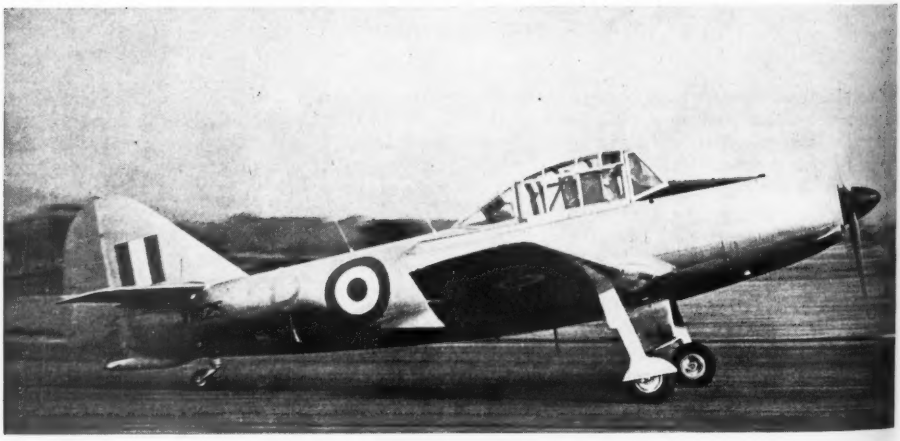


Fig. 29.
Avro Athena Mk. 1 aircraft.

generator fitted in the rear of the propeller.

The propeller is arranged with the usual constant speeding control and can be fully-feathered. It is also suitable for use with power braking, a development which will be pursued at an early date.

The complete power plant weighs 1,400 lb., of which 400 lb. is accounted for by the propeller and its ancillary equipment.

To conclude this section on installation some pictures of aircraft fitted with Mamba engines are shown in Figs. 27, 28, 29 and 30.

Figure 27 shows the Mamba Lancaster, the original flying test bed, with the Mamba fitted neatly into the nose of the fuselage, thus making a strange five-engined aircraft.

The Boulton Paul Balliol shown in Fig. 28 is the prototype of an advanced three-seater trainer. The very clean lines of this machine and the excellent forward view are largely due to the small size of the Mamba engine.

Figure 29 shows the Avro Athena, an aircraft to the same specification as the Balliol and similar in appearance and performance.

The Armstrong Whitworth Apollo, shown in Fig. 30, is a new air liner and the illustration is of a model of the aircraft which is now under construction. The small frontal area of the four Mamba engines is noteworthy.

## CONCLUSION

This paper has attempted to give a correct, if condensed, account of the development of the Mamba engine. This process is by no means complete, but it is hoped that the steps taken to turn a new idea into a serviceable aero-engine will have been of interest.

Apologies are offered for the omission of some aspects of the problem and for the necessarily sketchy treatment of the items which have been included. Many of these could quite easily form a suitable subject for a paper on their own account, but it is hoped that sufficient has been included to give a fair picture of the progress made.

My thanks are due to Armstrong Siddeley Motors Limited, for allowing me to give this paper; to the officials of the Ministry of Supply for allowing the publication of work done for them; and to outside firms who have helped in the development of the engines. Finally, I would like to thank my colleagues at Parkside for the help they have given in the preparation of the paper.

# DISCUSSION

**G. R. Edwards** (Vickers-Armstrongs Ltd., Weybridge, *Fellow*): He congratulated Mr. Lindsey on what he knew to be, from his association with the Mamba, a completely honest and factual dissertation on the development of the engine. It was most refreshing to have the goods weighed up just as they were, whether good or bad. Mr. Lindsey had said the reason they went for an axial compressor engine was because it

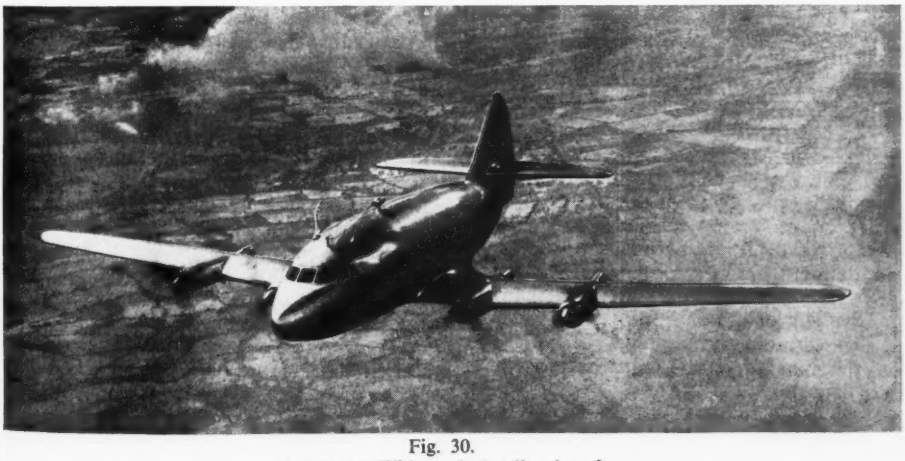


Fig. 30.
Armstrong Whitworth Apollo aircraft.

would be very efficient and they could make it smaller. He thought there were other aspects to be considered.

The lack of background which that type of engine had was, he thought, one of the things which would have been considered, particularly from the point of view of its prospective reliability. They had to remember that so far as its civil application was concerned all other engines that had been put into civil aeroplanes for many years past had previously had a large amount of military development work. It might be that the propeller-turbine was intrinsically such a good piece of engineering that it would not have to suffer in the same way that the average piston engine had and would be free from protracted and painful development troubles when it got into an aeroplane. He thought it fair to say that the evidence so far confirmed that view—that the propeller-turbine engine was basically right. But he suggested that the first step in committing passengers to turbine engines, whether with propeller or not, might well be through an engine with a centrifugal compressor, because centrifugal compressors had been running in piston engines for many years. There was their rugged construction and freedom from icing troubles, which he thought would not be present to the same extent in an axial compressor. Mr. Lindsey's comments on that would be welcome.

Fifteen months ago he was sceptical about the propeller-turbine position, largely because so much facile optimism had been expressed that he thought the true development which the engine had obviously got to go through was being overlooked and it was not getting its fair chance. The stage that had been reached now was obviously one where they could accept the propeller-turbine as being a tried piece of equipment.

The evidence of several aeroplanes that had flown with the propeller-turbine had convinced some of them that the addition of the propeller to the turbine engine did not necessarily do it any harm; it apparently did not detract from its smoothness, and in many respects added much that was good. The propulsive efficiency was improved and it made it a much more workable proposition, so far as the medium speed commercial aircraft was concerned.

The propeller brought with it some control problems. The normal control of the aeroplane and the propeller with its engine he believed to be completely solved. He had seen propeller-turbine engines treated in a manner which a good many piston engines would not have tolerated. He had seen sudden acceleration and sudden deceleration applied without the engine complaining or the constant speed unit complaining. He thought some of the devices to guard against a sudden increase of drag would cause them some trouble and he thought they should seriously consider getting rid of some of them. To promote argument, he suggested that one way would be to go to an engine with a two-stage centrifugal compressor with a free power turbine.

With regard to the small diameter he would warn prospective fitters of the propeller-turbine to be wary. The radiant heat that came from the hot part of the engine had a certain distance before it impinged on some of the things that made the engine work —some of the cables and pipes and other bits —and they would be apt to get a bit hot if they were put round the combustion chamber. In that connection small diameter cowling could be a snare and a delusion. Further, the difference that three or four inches in diameter made on drag in a machine that was not likely to go much above 300 miles an hour was not very great.

There had been a fair amount written to the effect that although they had got behind the Americans at the end of the war, the time was shortly coming when Great Britain would be in front. Not slightly in front but years and hundreds of miles in front. The Mamba and other engines in this class were some of the most potent means they had of gaining that lead. The engine designers had done the airframe designers proud, for they had produced something which no one else in the World had yet done, and got it to a stage of development far in front of any rival in any country—two or three years in front. If, as a nation, they did not cash in on that fact, then the two or three years' lead would vanish and they would again be trying to think of excuses to justify it.

**Air Commodore F. R. Banks** (The Associated Ethyl Co. Ltd., *Fellow*): They might be interested to hear the reasons which led to the building of the Mamba, for it occurred during his time at the Ministry of Aircraft Production.

The Air Ministry decided that the new Royal Air Force trainer should be fitted with a propeller-turbine. And, although the engine

people were well aware that it would be difficult to meet the (engine) dates for the two airframes of Boulton Paul and Avro, it was confirmed that the work on the two propeller-turbines, the Rolls-Royce Dart and the Mamba, should proceed.

The Dart incorporated a two-stage centrifugal compressor in its design, and the Ministry also wanted to see whether a small axial blower would be satisfactory for this size of engine. Mr. Lindsey's firm had justified the Ministry's choice of an alternative engine when the Mamba was built.

If they looked at the curve of the Mamba development which Mr. Lindsey had shown they would see that the engine had made fairly steady progress and, in the second or third year, between 2,000 and 3,000 hours' development running had been done; which was quite a lot and showed that there were no really bad snags in the basic engine design.

He agreed with Mr. Edwards on the question of engine robustness for civil aircraft and thought that the centrifugal blower might have some advantage over the axial type in this respect; always provided that the operating economy of the engine did not suffer due to any lower efficiency of the former.

There was another reason why they wished to build a 1,000 shaft h.p. engine; they felt there would be a pressing need for such an engine, or for one of slightly higher power, in the civil aircraft field. The Brabazon Committee had already made its recommendations and it seemed, at the time, that there would be advantages in having a four-engined aircraft from the point of view of overall safety of operation and, in particular, to avoid the results of the ever-present danger of an engine failure at take-off; and a machine of about 40,000 or 50,000 lb. all-up weight, having four such engines, would give a very good performance.

There had been a number of views on gears and a lot of people said that the spur-type gear, after some early failures, would not work. He had never held that view and considered, with one notable exception, that they had gone too lightheartedly into the gas turbine gear business. It had since been proved that the spur-type gear worked quite well and gave little trouble, if properly designed and accurately made in the first place. He felt that the best compromise would probably be the single or, perhaps, double helical gear for the high speed train with spur gears for the final propeller drive.

Mr. Lindsey's firm had done a good job in connection with combustion chamber development and their vaporising chamber had given excellent results and would probably be one of the best ways of ensuring proper combustion at all flight conditions. This development, he thought, would lead finally to a reliable annular type combustion chamber which, of course, had great value in reducing overall engine diameter, particularly in the case of large engines. But the annular combustion chamber would only be used when it could be operated without attention for at least as long as the engine itself, between servicing periods.

He favoured the system incorporating the free turbine wheel which drove the propeller, with no mechanical connection between it and the turbine wheel driving the compressor. He would like to know what Mr. Lindsey now thought about this after his experience with the integral system?

The free turbine arrangement should allow some degree of over-speeding in order to improve the static thrust of the propeller for take-off; the Americans had been rather worried about loss of static thrust in the case of propeller-turbines where the propeller was connected to the compressor system.

**R. J. B. Woodhams** (A. V. Roe & Co. Ltd., *Assoc. Fellow*): They had been flying with Mamba engines in the Athena for some time now and whereas before operating with an actual engine they were somewhat sceptical of its possibilities, they were now completely sold on these gas turbines. He thought that the fact that Armstrong Siddeleys had produced an engine of radical new design in only two years was to their credit.

One point that struck him as odd was that presumably they had used a standard type of c.s.u. for the Mamba as an expediency, and had involved themselves at the same time in a lot of complications. There was a suggestion that on one of Mr. Lindsey's curves it would appear that jet top temperature could be used for controlling the airscrew pitch, while the engine speed could still be controlled by throttle.

In the paper Mr. Lindsey mentioned using an eight horse power motor for starting. That seemed a lot of power, and assuming 24 volts, eight horse power meant 450 amp. cables. Was that eight horse power based on starting at $-20°C$. or not? He noticed that the position of the auxiliary drive shaft had been changed on the Mamba II from the bottom

to the top. Could Mr. Lindsey give any assurance that the bottom position was optional?

**R. J. Shire** (Rolls-Royce Ltd.): Five thousand hours of development running was an indication of the magnitude of the work entailed in the design and development of a job of that nature. Mr. Lindsey and his team were to be congratulated on passing so many mile stones, so early in the life-time of the engine.

Would Mr. Lindsey amplify his remarks on a few of the problems. In particular:—

1. Did he experience any uneven bedding on the reduction gear teeth, and were any precautions taken to ensure that each layshaft took its fair share of the load?
2. Did he retain the rollers in the broach pockets of the bearing cages?
3. Had aluminium cages of the one-piece construction been tried on the main high speed shaft?
4. Mr. Lindsey had shown them how an axial compressor could be made to work, and work efficiently. He claimed the advantage of small area, but the full advantage of that would not be taken until the aircraft designer buried the installation in the wing. For single engine installation there was plenty of room to accommodate a much larger, even a centrifugal type of engine, and while the aircraft man insisted on folding up the undercarriage behind the engine, it was the undercarriage rather than the engine that limited the diameter of the nacelle at the moment.

   He gathered from the American technical press that they were considering steel blades for axial compressors on account of their increased fatigue strength, to give more robust construction, and possibly less expansion. Did Mr. Lindsey think it would be necessary to use steel blades throughout and accept the increase in weight?
5. They entirely agreed that improved efficiency of the turbine was most essential to that type of engine, and they would be interested to hear how five per cent. increased efficiency might be realised. Did Mr. Lindsey think there was a future for hollow air-cooled turbine blades?
6. Little had been said on the coupling between the turbine and compressor; he would be interested to know how this was assembled and locked and did the splines interfere with the spherical and cause fretting?

**E. S. Moult** (de Havilland Engine Co. Ltd., *Fellow*): He was impressed by the improved pressure ratio and efficiency of the Mamba 2 compressor and would like to know whether this improvement arose from the change in the hub/tip ratio as described, or from some simultaneous change in blade design. He thought an efficiency of 87 per cent. for a pressure ratio of 6 was a very creditable achievement and particularly so when associated with the flatter characteristics shown in one of the other figures.

A feature of the vaporising combustion system was the low fuel pressures employed. This was helpful from the point of view of pump design and the keeping of tight joints but he had wondered if it had involved any difficulties when cruising at altitude. He presumed that the relationship between fuel flow and pressure followed something like a square law and therefore the operating fuel pressure at reduced duty at altitude could be very low indeed. Even the distance between the top and bottom burners might then influence the flow to individual burners. Had there been any troubles in fuel distribution arising from these low pressures?

A further point which should be mentioned was the economics of small engines. Unfortunately there were just as many components and just as many accessories and gadgets in a small gas turbine as in its larger counterpart and this fact reflected adversely on the cost per unit of power. He did not wish to draw any exact parallel, but the small gas turbine was perhaps at a greater disadvantage in this respect than the small piston engine where a reduction in the number of cylinders was permissible. A corresponding reduction in compressor and turbine stages did not appear possible if a competitive specific fuel consumption had to be offered. The Armstrong Siddeley Company had now had experience with both types of prime mover in the smaller sizes; would Mr. Lindsey care to venture any views on the relative costs per unit of power on a basis of equal rates of production?

**N. E. Rowe** (British European Airways, *Fellow*): He had been impressed by Mr. Edwards' remark that the engine industry had presented them with a first rate development and that they could cash in on it. He did not think it could be done on civil aviation only

because the total of civil aviation requirements could be met by a comparatively small number of engines. Therefore he would like to see it used in military aviation.

Another point was the development of the engine and how they could get the development done without a widespread use in aeroplanes. This was one of their major problems in the development of the new propeller-turbine engines. They had not had in the past many vehicles in which to put them and so obtain a wide experience. It might be that it was not necessary, but he thought differences could be found in different installations and if widespread experience could not be gained of the engines in flight, then it might be well to try to get some approximation to those differences on the ground. In effect he was suggesting that they should try to simulate air conditions in ground rigs so closely that the ground test could be made to yield experience equivalent to air testing. It was a problem that needed careful thought otherwise the development of these engines might be severely handicapped.

How far had the 6 to 1 compression ratio and the 87 per cent. efficiency shown in the lecturer's curves been designed for? It seemed possible that these high values were in part at least, fortuitous, which implied significant gaps in knowledge in these matters.

He did not think the engine was really yet developed. There was a severe problem of civil aviation, namely icing, that had to be faced because it might mean further special modifications of the design. He was thinking not only of the entry, the blades of the compressor and so on, but also the icing of the ducts to the second stage of the engine installation where the piping, controls and so on passed from the back to the front of the engine over the combustion chamber. If that entrance got iced up the temperature would rise rapidly inside the chamber. A great deal of the wiring and controls passed through it. What were the lecturer's views?

**J. J. Bukovsky** (College of Aeronautics, *Associate*), *contributed*: He would like to ask the following questions on problems which were causing quite a lot of thought and trouble elsewhere:—

1. He had heard recently that in America they were trying to solve the main part of the problem of the control of propeller-turbines by using a pneumatic system thermometer (two orifices method) in the combustion chamber. According to the promising results they obtained, this might prove quite satisfactory, as this type of indicator provided sufficient output force to operate directly a pilot valve on a fuel flow control system. Another good feature of this method was the quick response of the indicator, so that the temperature in combustion chamber and its variations might immediately actuate the control mechanism of the fuel flow. Had this possibility been considered?

2. On the Mamba combustion chamber, he understood that the original Lindall type vaporising system had been left because of the two fuel entries requirement (using the pilot burner) and after the modified A.S.X. pre-heater type had been changed to the present "walking sticks" vaporising system, which proved to be quite satisfactory. As it seemed that in the future development of turbo-propeller engines, it would be necessary to use the annular combustion chamber and the vaporising system again, instead of standard single flame tubes and normal fuel injection burners, could Mr. Lindsey comment on the possibilities of the "walking sticks" vaporising system in the annular type of combustion chamber, and what modifications to the system would be required, bearing in mind the necessity of uniform flame distribution round the whole combustion region?

3. The problem of de-icing propeller-turbines had been mentioned, and no doubt this problem would be solved satisfactorily before long. A similar, although not so serious, problem was that of strange particles passing through the axial propeller-turbine combination, and avoiding the passing of those particles through the engine generally. In a centrifugal type of jet engine this was not really a very serious problem, but in the axial type of jet—and propeller—engine it was. Many different types of stone or debris guards had been suggested, both in Great Britain and in the U.S.A., but not one was really satisfactory, bearing in mind especially the possibility of the icing of those devices. He would be glad of the lecturer's comments on these problems.

4. Air Commodore Banks' mention of the free turbine had impressed him, but although the free turbine was theoretically an excellent solution to many problems in propeller-turbine design, many mechanical problems must be solved before a successful construction of a free turbine could be achieved.

Would Mr. Lindsey give them his ideas on the possibilities of a free turbine in propeller-turbine engines of the future?

**A. W. J. Smith** (*Associate*), *contributed*: He would like Mr. Lindsey's opinion on the following:—

1. Should the power fail on a turbo-propeller type engine, Mr. Lindsey pointed out, the danger was that the propeller "fired" right off very rapidly, causing violent drag and yaw reactions; the same might occur with c.s.u. failure or failure of the oil system. To counteract this, automatically, with no extra mechanical complexity, other than an increase in oil pressure, why could not a reversion be made to the counter-weight type of propeller? This had the tendency, of course, to go to coarse pitch automatically. Could not an ordinary hydromatic propeller be so modified and provided with higher oil pressure to overcome the counter-weight effect during normal use? Perhaps the weights need only be heavy enough or at just sufficient radius to counteract the natural blade tendency to "fire" off?

2. Mr. Lindsey mentioned the difficulties of harnessing the turbine to the compressor. Had anyone ever attempted a turbine on the lines of a large drum, with the compressor blading at the inlet end, internal to the drum, the combustion chamber in the centre and the turbine blading at the other end, internal to the drum—the whole with a rigid centre portion carrying the fixed vanes for the compressor, the turbine and the fuel supply lines? If this could be done, perhaps the advantages would be:—

(*a*) A highly rigid turbine - compressor coupling.

(*b*) If the turbine blades had a tendency to creep under centrifugal loads with high temperatures, they would be subject to compression in place of tensile loading resulting in a lower creep rate.

(*c*) The combustion space could be annular and of large volume and cross-sectional area.

(*d*) The bearings could be of any desired dimensions.

(*e*) The turbine (resembling a spoked wheel) could be made with no large masses of metal to become "temperature saturated"—provided that the turbine could be designed to withstand the tendency to "burst" under centrifugal loading.

Provided that the temperature variations over the drum could be successfully overcome it seemed that the type might have several advantages — it should, at any rate, be much lighter.

3. Apart from the possibility of carbon blockage, was there any reason why a low pressure, spring loaded, pintle type of injector should not be used in a jet engine? Used successfully in piston engines with bulk injection, it would seem to be suitable for high altitude, low flow conditions as a safeguard against "dribble," to have no friction surfaces liable to cause "stiction" when used with paraffin and to facilitate the use of much lower fuel pressures. The spray pattern would seem to have a good chance of remaining steady over a wide range of flow.

**M. T. Woodcock** (D. Napier & Sons Ltd., *Assoc. Fellow*), *contributed*: He was engaged on the design and development of combustion chambers for gas turbines and was most impressed by the development of the vaporisation combustion chamber. He would like to ask the following questions:

1. Was any difficulty experienced during starting, *e.g.*, long flame length or slow acceleration to maximum speed from a cold start?
2. Was there any carbon formation in the primary tubes after, say, 50 hours?
3. What was the air-fuel ratio in the primary air tubes, and (*b*) the vapour temperature on leaving the primary air tubes, both for maximum power conditions?
4. In order to give complete vaporisation of the fuel was the required surface area of the vaporisation tubes determined by experiment, or calculated and what was the approximate value of the overall conductance of the system?

## MR. LINDSEY'S REPLY

**Mr. Edwards:** He agreed with Mr. Edwards on the question of controls. The point that must be borne in mind was that the existing propeller control for the Mamba engine worked very satisfactorily and the engine possessed all the virtues referred to by Mr. Edwards. In addition, adequate provision was made as described in the Paper for the case of an engine failure. The complications began when a c.s.u. failure was considered and it was this type of failure which

had necessitated the incorporation in the mechanism of a removable stop. What was really required was a propeller and c.s.u. combination which would fail safe. While the problems were different with a free turbine engine, this introduced new problems in propeller control and these problems would not necessarily be any easier to solve. He did not think that an engine having a two-stage compressor and a free turbine would be a better solution but this was, of course, a matter of opinion.

As regards difficulties with aircraft parts adjacent to hot portions of the engine becoming overheated, experience had shown that so long as adequate radiation shielding was provided and that the space outside the shielding was ventilated these troubles did not occur.

According to Mr. Edwards, the Mamba had developed from being an engine without a future to an engine with no background, which was a big step forward.

**Air Commodore Banks:** He thanked Air Commodore Banks for his remarks and confirmed his ideas of the yearly development running times. These were approximately 220 hours in the first twelve months, 2,600 hours in the second twelve months, and 2,800 hours in the last eight months.

With regard to the questions about restriction on take-off thrust for a direct coupled engine such as the Mamba, he agreed that there was some deficit but, so far, it had not been at all serious in any aircraft application. The deficit was most severe when, due to other restrictions such as the need for specially low tip speed to reduce the noise level in cruising conditions, the tip speed at take-off was unduly low. In actual fact the propeller fitted to the Mamba engine produced about 2.4 lb. thrust/h.p. without exceeding a reasonable tip speed under cruising conditions.

**Mr. Woodhams:** Mr. Woodhams had commented on the choice of a normal c.s.u. control for the propeller pitch instead of, for example, jet pipe temperature. He was not convinced that any other fundamental different type of control was necessarily superior and undoubtedly such controls would have their own troubles. He did not think that even starting again, he would make any different choice.

The Mamba normally required 8 h.p. for starting and he did not consider this to be an excessive figure.

With regard to the position of the accessory drive shaft on the Mamba Apollo power plant, this was peculiar to this power plant and there was no indication of altering the trainer type of Mamba.

**Mr. Shire:** The proportioning of the load equally between the three planet gears was achieved by allowing the annulus gear to centre itself on the three planet gears.

The rollers in the broached cages were not retained but were merely loose in the broached holes.

The main roller bearings still used built up cages as these worked very satisfactorily and it had not been necessary to adopt the more expensive broached cage.

He was not yet convinced that using steel blades in the compressor was desirable. Steel blades would certainly make the compressor more robust but would also make the compressor very much more expensive. A good compromise might be the provision of steel blades in the early stages of the compressor.

Whether turbine efficiency could be increased by 5 per cent. was dependent, of course, upon the existing turbine efficiencies. He merely thought that efficiencies of the Mamba turbine, in the course of time, could be increased by about 5 per cent.

The coupling between the turbine and the compressor through the articulated joint was accomplished by means of internal and external mating gear teeth.

**Mr. Moult:** The differences in efficiency shown between the Mamba 1 and Mamba 2 compressor was partially due to development improvements in the compressor which had also now been applied to the Mamba 1 compressor, but mainly due to the increase in size which had resulted in a fundamentally better compressor.

The low fuel pressure required for the combustion chambers meant that at very small flows special arrangements had to be made to achieve good distribution. This took the form of a distributor having submerged jets so arranged internally as to defeat the "square" law.

It was agreed that the 1,000 h.p. class was probably the most difficult field to enter for a gas turbine engine, but even so a very good case could be made for using a Mamba engine in place of a corresponding piston engine.

The cost of the gas turbine engine in default of reasonable production orders was difficult to estimate, but a figure of £6 per

take-off h.p. was thought to be a reasonable estimate.

**Mr. Rowe:** He agreed with Mr. Rowe that any engine depending solely on the civil market for its development would be severely handicapped. It was essential that the engine should be used in a military machine to obtain the necessary flying background quickly on a large number of engines. Whether any type of bench testing could simulate flying conditions closely enough to replace this necessary experience was doubtful.

The design target for the compressor performance was a compression ratio of 5:1 at 14,500 r.p.m. with an efficiency of 86 per cent. The better figures quoted for compression ratio were achieved at an overspeed condition.

Much work on de-icing was being done at the moment and they were convinced that an engine could be adequately anti-iced by thermal means. In some respects the Mamba was a help in this respect as no half measures would do and once the problem of anti-icing had been solved it should give no more trouble. Some time would naturally elapse before a satisfactory solution would be found, but he ventured to forecast that in two years' time there would be no problem left.

**Mr. Bukovsky:** There had been many suggestions, both here and in America, for using jet pipe temperature or combustion chamber temperature as the control signal for propeller pitch instead of the c.s.u. Such a change, however, would not solve the problems which were worrying them at the moment and, although it might provide a fundamentally better control system, this had by no means been proved; indeed, apart from the unpleasant results of a mechanical failure of the present system, this worked very well indeed.

The "walking stick" type of combustion chamber as used in the Mamba was developed primarily to shorten the combustion chamber. It had the advantage of being ideally suitable for use in an annular type of chamber and all that was required for the conversion was a re-disposition of the "walking sticks" and the secondary air pipes round the annulus.

If debris guards were to be used on an engine they would have to be fitted downstream of the thermal anti-icing arrangements, thus avoiding the possibility of icing-up this guard.

The relative merits of direct coupled and free turbine engines was much too difficult a subject to be discussed here. Both systems had their advantages and disadvantages from a point of view of engine construction and propeller control and problems would occur with both systems.

**Mr. Smith:** The provision of counter-weights to remove the tendency for propeller blades to fine off under centrifugal force was only a partial solution to the problem of a c.s.u. failure. Counter-weights of sufficient size would be very heavy and extremely difficult to arrange inside a spinner and it would only be effective in a type of failure in which the c.s.u. left the propeller blades uncontrolled, for example, a complete oil failure.

It would not be possible to make the counter-weights powerful enough to insist that the propeller went "coarse" in the type of failure in which the c.s.u. selected "fine" incorrectly.

The suggestion of the drum type of engine was ruled out from a stress point of view. It would be quite impossible to make a drum of the type described strong enough to withstand the rotational speeds necessary for achieving present day compressor and turbine performance.

He would refer Mr. Smith to authorities better capable than himself to answer the question of the possibility of using pintle type spray injectors in combustion chambers. As their vaporising type chamber removed the necessity for spray jets of any type they had not had to consider this problem.

**Mr. Woodcock:** Although special provision had to be made in the vaporising chamber for starting, this had proved successful and gave no trouble with long flame length or slow lighting up.

They had no trouble whatever with carbon formation in the primary tubes and, in fact, the whole chamber was free from carbon up to a period of at least 500 hours, which was the longest run they had done without attention.

The air fuel ratio in the primary air tubes was about 3/1 and they estimated the vapour temperature as being 180°C. at sea level static condition.

The required surface ratio for vaporising was determined largely by direct experiment and if too much surface were provided, trouble was experienced with over-heating of the vaporising surfaces.

# ESTIMATION OF CRUISING AIR SPEEDS FOR ECONOMIC ANALYSIS

by

ALAN H. STRATFORD, B.Sc., A.F.R.Ae.S.

## INTRODUCTION

IN the course of investigation into the operating economics of transport aircraft, the cruising speed arises as a fundamental variable and a rapid method of correction of speed for variation of power, height and weight is frequently required. Other problems present themselves, such as the estimate of cruising speeds in the course of a new type design study, or the correction of a "one-point" published performance of a new aircraft to a standard operational condition differing in specified weight, altitude or power output for cruising.

In this note no account will be taken of the block speed correction arising because of the modification of true air speed by the various factors, such as wind, climb and glide which distort the optimum flight path.

The principle of the method here suggested involves the unique relationship of $p$, the ratio of thrust power required at any speed ($V$) to the thrust power at the minimum drag speed ($u$) at the same altitude, and $n$ the well-known speed ratio $V/u$. In the case of *ab initio* estimation of the cruising speed, $V$, from the design parameters of the aircraft, the additional step of calculating the thrust power required at the minimum drag speed, $u$, at the operational height, $h$, must be taken. In all cases it is assumed that $C_{do}$ and $\eta$ can be estimated beforehand or have values already known.

The following symbols are used in the analysis and have the significance indicated:

$V_c$ = Cruising speed at operational altitude (m.p.h.)
$h$ = Operational altitude (ft.)
$\sigma$ = Density ratio at $h$ (ft.)
$B_{vc}$ = Cruise B.H. power at $h$ (ft.) at $V_c$
$P_u$ = Thrust power at minimum drag speed, $u$
$\eta$ = Airscrew efficiency
$u$ = Minimum drag speed (m.p.h.) at $h$ (ft.)
$n$ = Ratio: $V_{c/u}$
$p$ = Ratio: $\eta \,.\, B_{vc}/P_u$
$W$ = Gross weight (lb.) of aircraft at $h$ (ft.)
$w_L$ = Wing loading (lb./sq. ft.) corresponding to $W$
$C_{do}$ = Overall drag coefficient
$A_e$ = Effective aspect ratio
$E$ = Maximum lift/drag ratio
$\rho_o$ = Sea level air density (slugs cu. ft.)

Subscript 1 indicates initial condition.

Subscript 2 indicates final/second condition.

The relations upon which the attached figures have been based are:

Fig. 1. $u = \left(\frac{w_L}{\rho_o \,.\, \sigma}\right)^{\frac{1}{2}} \left(\frac{4}{C_{do} \,.\, \pi \,.\, A_e}\right)^{\frac{1}{4}}$

Fig. 2. $p = \frac{1}{2}(n^3 + n^{-1})$

In the general analysis drag power at any speed $V_c (= n \,.\, u)$ was written as:

$$\eta \,.\, B_{vc} = \left(\frac{W \,.\, u}{750 \,.\, E}\right)(n^3 + n^{-1})$$

where $E = [\pi/4 \,.\, A_e/C_{do}]^{\frac{1}{2}}$

and drag power at speed, $u$ $(n = 1)$

$$= \frac{W \,.\, u}{332\,(A_e/C_{do})^{\frac{1}{2}}}$$

Paper received November 1948.

Mr. Stratford is Direct Costs Engineer with the British European Airways Corporation.

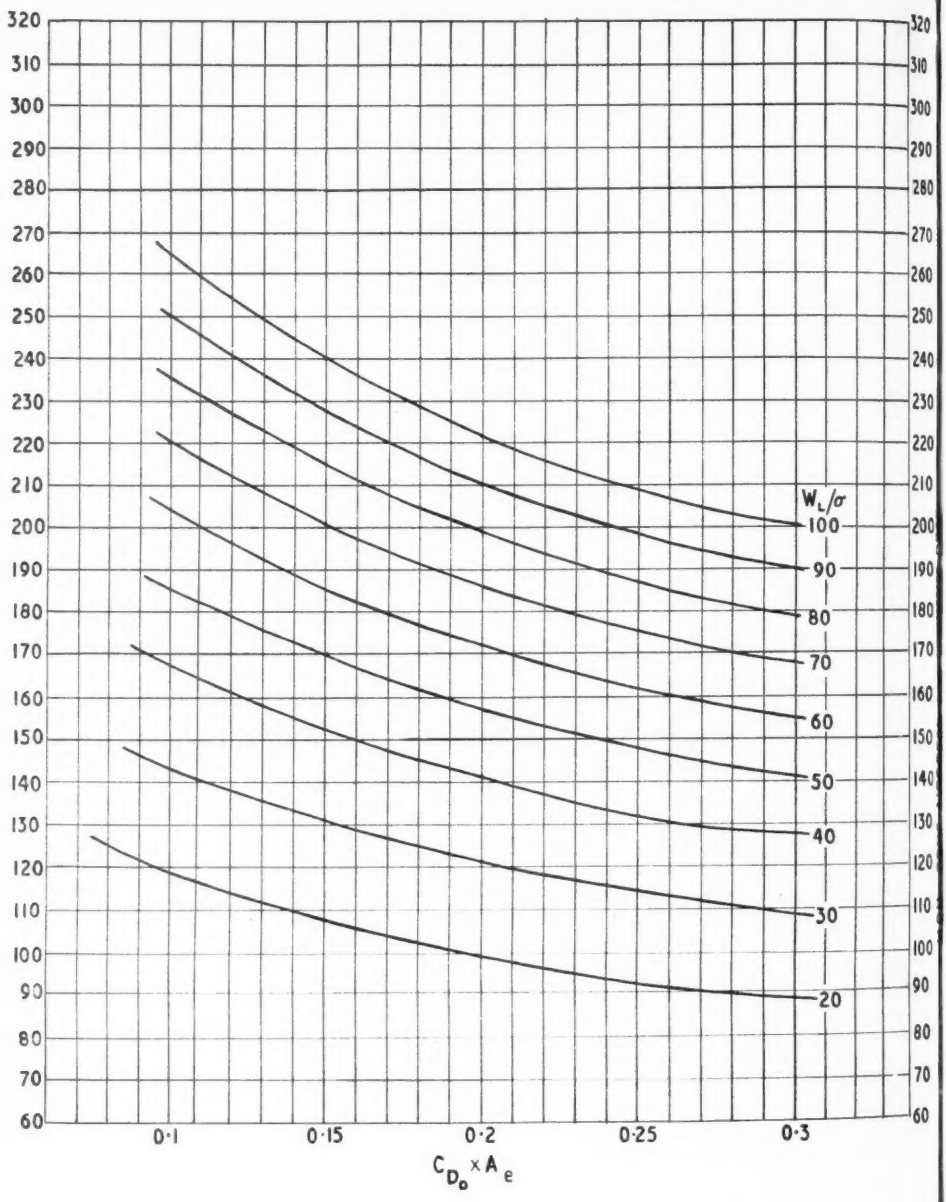



Fig. 1.

Variation of minimum drag speed with $C_{D_o} \times A_e$ and $W_L/\sigma$.

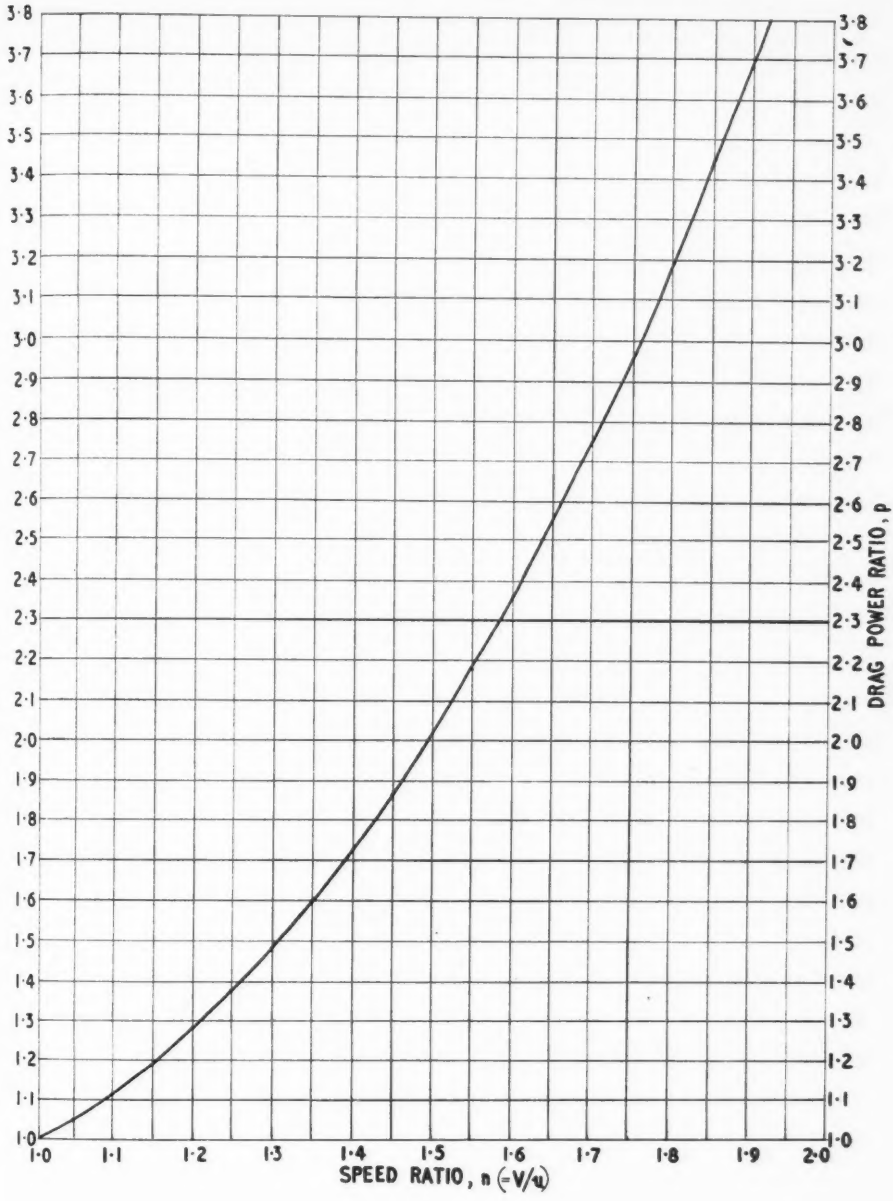



Fig. 2.

Variation of drag power ratio, $p$, with speed ratio, $n$.

## 1. CALCULATION OF TRUE CRUISING SPEED FOR DESIGN STUDY

Data: $W$, $w_L$, $C_{do}$, $A_e$, $B_{vc}$, $\eta$ and $\sigma$ at cruising height.

(*a*) Calculate $w_L/\sigma$ and $C_{do} \cdot A_e$ and find $u$ from Fig. 1.

(*b*) Calculate $P_u = \dfrac{W \cdot u}{332 (A_e/C_{do})^{\frac{1}{2}}}$

(*c*) Calculate $p = \eta \cdot \dfrac{B_{vc}}{P_u}$ and find the corresponding value of $n$ from Fig. 2.

(*d*) Calculate the required cruising speed
$$V_c = n \cdot u$$

## 2. CALCULATION OF CORRECTED TRUE CRUISING SPEED AFTER ALTERATION OF OPERATIONAL PARAMETERS

The unique relationship of $p$ and $n$ may be used to solve a number of simpler problems which frequently arise in economic analyses and comparisons.

We take here the general case which allows for a variation in cruise power and/or airscrew efficiency, cruise altitude, and flying weight.

Data here are likely to be:
Initial $W_1$ $w_{L1}$ $B_{vc1}$ $\eta_1$ $\sigma_1$ $V_{c1}$ $C_{do}$ and $A_e$
Final $W_2$ $w_{L2}$ $B_{vc2}$ $\eta_2$ $\sigma_2$
It is assumed that $C_{do}$ and $A_e$ remain constant and it is required to find the new cruise speed $V_{c2}$ for the final values of the above parameters.

(*a*) Calculate $\left(\dfrac{w_L}{\sigma}\right)_1$ and $C_{do} \cdot A_e$ and find $u_1$, from Fig. 1.

(*b*) Obtain $n_1 = \dfrac{V_{c1}}{u_1}$ and read $p_1$, from Fig. 2.

(*c*) Calculate $\left(\dfrac{w_L}{\sigma}\right)_2$ and read $u_2$ the new minimum drag speed for the same value of the product $C_{do} \cdot A_e$ from Fig. 1.

(*d*) Calculate $p_2$ the new thrust power ratio from the equation:
$$p_2 = p_1 \cdot \frac{B_{vc2} \cdot \eta_2 \cdot W_1 \cdot u_1}{B_{vc1} \cdot \eta_1 \cdot W_2 \cdot u_2}$$
Clearly when one or more of the operational parameters remains constant some simplification of this relation will be possible.

(*e*) Fig. 2 will enable the value of $n_2$ corresponding to $p_2$ to be found.

(*f*) $V_{c2} = n_2 \cdot u_2$ m.p.h.

# AN AIRLINE'S ENGINEERING SERVICE EXPERIENCE AND ITS USE IN THE DESIGN OF TRANSPORT AIRCRAFT

by

H. S. CRABTREE, B.A., A.F.R.Ae.S.

The paper "Aircraft Servicing" by Norman and Wilkinson published in the November issue of the JOURNAL demands the close attention of both operators and aircraft manufacturers. The suggestions made can be further developed.

## UTILISATION OF AIRCRAFT

There is little doubt that the attainment of higher utilisation rates is one, if not the ultimate, solution of the economic problems that face air transport. This is even more evident when the present-day capital cost per pound of complete but unladen weight of varying transport vehicles is compared.

| Type of Vehicle | Cost per pound weight complete but unladen |
|---|---|
| Transport aircraft pressurised | £3 to £5 |
| Double-decker bus | 3/- to 6/- |
| Ocean-going liner (12,000 to 30,000 tons displacement) | 9d. to 11d. |

TABLE I.

If this capital cost is then compared with the average utilisation rates now attained, and the total expected useful life of the three means of transport, the urgent need for pushing up the utilisation rates of transport aircraft is readily seen.

| Type of Vehicle | Present Average Utilisation Rate per annum in hours | Chief Reason for Limitation of Utilisation Rate | Average Working Life |
|---|---|---|---|
| Transport Aircraft | 1,460 to 2,920 | Service Engineering | 5 to 7 years |
| Bus | 5,110 to 5,840 | Lack of traffic offering during night hours | 7 to 12 years |
| Ocean Liner | 6,570 to 7,300 | Loading and unloading facilities | Up to 35 years |

TABLE II.

The ocean liner has the cheapest capital cost per pound of unladen weight, spends the greatest time each year carrying revenue-earning loads for its operators, and has the longest useful life.

The transport aircraft is the worst in all these respects, and if it were to be financially self-sufficient and not artificially backed by subsidies and other financial devices, its carrying rates for passengers and freight would be altogether beyond those of its older and slower competitors and, out of all proportion, even making allowance for the higher speeds at which it can move loads.

It will also be noted that both the older forms of transport have any further increase of utilisation limited by reasons and conditions outside their own direct control. The transport aircraft has its utilisation limited by its servicing requirements, a function normally carried out by the operators themselves and entirely under their own control.

The first problem therefore that lies before the aircraft operators if they are to improve their economic position, is the reduction of elapsed time which their engineering departments require to service their aircraft.

Paper received January 1949.

Mr. Crabtree joined Imperial Airways Ltd. in 1934 and has had wide experience at home and overseas, ranging from development work on the Empire boat and other aircraft for Imperial Airways, to overseas operations and to maintenance and overhaul engineering on a large variety of Civil landplanes. Since 1948 he has been working on the development of B.O.A.C.'s special freighter services.

This reduction, it would appear, can be achieved by the combination of several methods:—

1. Increasing the efficiency of the methods and means of maintenance and overhaul work on aircraft.
2. Reducing the amount of work to be done.
3. Making what work has to be done easier to accomplish.

Messrs. Norman and Wilkinson have already indicated one of the lines along which the efficiency of maintenance and overhaul engineering procedures can be raised. Their suggested methods revolve round the changing of units at specific periods of time, based on knowledge obtained in various ways of the safe life of such units. Although this has been the aim of most of the leading airline engineers for a number of years, coupled with the development of a "snag shooting" technique which is based on trial and error methods applied in logical sequence of possibilities for each trouble that arises, progress has been slow, possibly because many airline engineers have been forced to work in conditions of factual ignorance.

The basis of all such aims, however, depends on factual evidence. This can be collected by the accurate recording and careful practical analysis by the aircraft operator of his day-to-day engineering experience. Such a collection of facts can be the only solid basis of all thinking by airlines, not only on their own engineering organisation, practices and procedures; but also on the engineering requirements of their new replacement aircraft.

With accurate and careful analysis of this previous experience, the operator should be able to reduce on existing aircraft his maintenance work to a level where he can be assured that no unnecessary work is called for on his maintenance schedules, or done on his aircraft.

By constant review of the maintenance schedules and the engineering records, tendencies and trends can be noted and steps taken by changing the schedules on existing engineering practices and procedures and taking possible modification action to meet foreseen, and thus often calculable, developments. Aircraft servicing will be working on facts, and will be immediately aware of changes due to increasing life and experience. It will no longer be dependent upon the opinions of a number of junior inspection staff working with little factual guidance.

But real progress towards reducing aircraft servicing time will never be achieved until both the aircraft operators and the manufacturers appreciate that such reduction will only be achieved by designing aircraft, especially the detailed engineering aspects of aircraft, around this accumulated past experience of the operators.

It is the collection and presentation of this experience in which the manufacturer of a new type of aircraft is interested. Yet if the operator is to gain the utmost benefit possible from the study of his own engineering results, it is the constant reviewing of this experience as thrown up by his technical records and cost statistics, that must be for ever prompting him and guiding him to make changes in his engineering procedures.

The rule of an operator's engineering department should be to plan his future engineering requirements by working in the present time on the accumulated experience of the past.

## TECHNICAL AND COST RECORDS

The true basis of any efficient business is the collection and presentation, in as simple a form as possible, of reliable technical cost records which can be used by all executive and managerial staff as a guide and measure for all decisions, organisations and procedures.

In air transport such records can be greatly simplified by using man-hours and material (spares) costs as cost indices. Such costs, to be of real use, must be closely tied into the current technical operational problems of the fleet being used; and their form must therefore be laid down by the engineering department itself.

For example, if on an existing fleet of aircraft persistent trouble arises on, say, pressurised cabin windows, the airline engineer wants to know the statistical position, *i.e.* the number of average window changes for 1,000 hours of flying, the average service life of the windows replaced, and the tendencies for these two figures to deteriorate with increasing age of the aircraft, or to increase as a result of technical development work and subsequent modification action he may have initiated.

Besides these technical statistics, he must also have the cost index, in man-hours expended on windows per 1,000 hours of air-

craft life and for the average life of the windows, as well as the material costs. As in the statistical records, he must have these cost indices cast up in such a manner that he can see whether his costs caused by the trouble are increasing or decreasing. His incidents of window troubles, in fact, may be increasing, yet his costs through careful planning action may be decreasing—or, equally probable, although through his own development and resulting modification action his incidents may be decreasing, his costs may be on the increase through bad planning and bad technical control of his hangars and workshops.

The intelligent and constant watch of these four essential sets of figures is the real basis for all solid engineering progress. With these tools, the airline engineer can assess the sources of the greatest unnecessary expense, and of the greatest delay on the ground and can establish at any one moment the units, systems and parts of his particular aircraft which are the chief cause of engineering labour and effort and hence, a limit to increasing aircraft utilisation. He can direct the energies of his assistants to the improvement of the worst of these difficulties and he can note the necessity of the avoidance of similar mistakes on future aircraft.

Above all, the airline engineer can measure the efforts of his staff in solving current problems by watching his cost indices and technical statistics. He is in the correct position of judging the results of his own decisions and directions and measuring the failure or success of his efforts or those of his staff, from the actual cost and technical results thrown up.

Much engineering development work depends for the final results on trial and error and is limited by financial considerations. It is essential in air transport that those who initiate suggestions for technical improvement should be responsible for carrying out their suggestions and should be able to see and judge at first hand the results obtained. Second-hand development work initiated by a staff in no way responsible for carrying out the work suggested, nor held responsible for obtaining the results they may have claimed, cannot lead to real efficiency and true progress.

## NEW IDEAS AND EQUIPMENT

During the past fifteen years, and particularly the past ten years, the airline engineer has seen the influx of a great number of new ideas and, as a result the embodiment in his new aircraft of equipment in ever-increasing quantity and complexity. In general the modern aircraft have become more difficult to "keep flying" because of the heavy increase of work necessary on the increasing technical gear to be serviced. No one objects to new equipment that produces a dividend, either in increased safety, payload, range or speed. But it is evident that much new equipment does not necessarily produce such a dividend. There are even instances of new equipment that could only have found its way on to civil transport aircraft because of some theoretical idea, the application of which has never been checked against its true effect upon the safety and payload of the aircraft, still less against its likely effect upon the servicing requirements of the aircraft.

Although costs and statistical records of previous experience cannot be used as a satisfactory measure to decide whether a new piece of equipment can justify itself on an aircraft, they can at least be checked for any possible pointer of likely effects on the servicing of the aircraft. Such action will often give a valuable indication of its best application to attain the cheapest possible servicing.

The simplification of civil transport aircraft is therefore of importance to the future of air transport. Simplification is likely to prove a far more difficult, and indeed more worth while, aim to achieve than the facile agreement to add this or that further complication in order to improve a certain point, or often overcome a difficulty already caused by the application of a previous complication.

A well-known British designer was overheard to say that he had come to the conclusion that, apart from the fact that he and his staff were simple people, they would have to design simple aeroplanes, because his production department only employed simple people. He might well have added that the operators have long since realised that they too are only simple people employing simple people, and that the advent of simple aeroplanes might well change the whole financial structure of the World's airlines and their operations.

## NEW AIRCRAFT

Over the years, an engineering department of any airline working on the principles already suggested, would build up a vital

fund of practical knowledge invaluable so soon as a new aircraft was under discussion. Such knowledge would be factual and would be free from all false theoretical or other fallacious thinking.

The presentation of such factual information to an aircraft manufacturer would enable the manufacturer to get at the whole story, as built up over a number of years, of any particular problem on which he might require guidance.

To continue the previous simple example. It would be possible for the operator to present to the manufacturer a complete technical history of the original window equipment on his existing aircraft and show, step by step, the incidents that had arisen and the various corrective actions that had been taken. Time delays for the maintenance, the overhaul and the embodiment of modifications through window failures, the costs accruing therefrom and the effect on paying load could all be indicated.

With such a history there could be no chance of the manufacturer repeating on a new type of aircraft, through ignorance of this previous experience, a mistake already embodied on an aircraft in service. Moreover, it is suggested that it is far better for an operator to present his past experience in this manner than to dictate to the manufacturer exactly how he shall design and make any particular part of an aircraft. If an operator stipulates the full details of any part of the aircraft he requires, to the manufacturer of the new aircraft, he might just as well set himself up to be an aircraft designer and build his own aircraft. He has for each such demand, to decide the boundaries of his demand beyond which he must leave the aircraft designer to make his own decisions. Turning to the example of the pressurised window, the operator may feel he would like to stipulate exactly the shape and material of the pressurised window itself. If so, should he not also stipulate in detail the exact design, material and tolerances acceptable, the manufacturing method of the seals, the exact design and methods of fixing the windows in the combing, the design of the combing itself, and of its fixation to the fuselage structure—why not then the fuselage structure itself?

Not only must he feed the aircraft manufacturer with a wealth of details, but also he must be prepared to assist and inspire similarly the manufacturers of subsidiary equipment.

## DIVISION OF RESPONSIBILITY BETWEEN THE MANUFACTURERS AND THE OPERATORS

Thus it will be seen that the operator will be responsible during the development and design stages of new aircraft for presenting his experience to the manufacturer, leaving the manufacturer to absorb and digest the information given, and through the assimilation of this factual information to produce designs that (*a*) avoid difficulties experienced in the past, and (*b*) appear to go some way towards improving operational results, as measured by previous costs and technical statistics.

The ultimate designs put forward by the manufacturer, on paper, may not meet the full requirements of the operator. At this juncture the wise operator will be careful to base his criticism on previous operational results and, if he has no previous operational data, to hold his peace. It is far better to accept a compromise that satisfies the designers on the many other technical difficulties often only known and appreciated by the designer, than to force the designer to changes which compromise other parts or systems of the aircraft merely to satisfy a bright idea or fad of some technician out of touch with day-to-day problems, costs and statistics of operations, and for which there is no real justification from previous operational costs or statistics.

It is so easy for the operator to usurp the responsibility of the designer and manufacturer, and it is equally easy for the manufacturer to ignore the operational experience of the operator. Criticism backed by factual data carries weight and will help convince the most sceptical.

One contract for one type of aircraft may cost millions of pounds. On it may well depend the well-being of the operator for ten years, as well as the very existence of the aircraft manufacturer. The intelligent collection, careful practical study, and accurate presentation of previous engineering experience by the operators appears, therefore, to be the best method of guaranteeing the improvement of their own economic future, by enabling the aircraft manufacturers to design and manufacture their aircraft, even down to the smallest details, on the factual knowledge of previous operational experience.

# REVIEWS

**Electric Resistance Strain Gauges.** W. B. Dobie, M.Sc., F.R.S.A. and P. C. G. Isaac, B.Sc., Assoc.M.Inst.C.E. English Universities Press Ltd., London, 1948. 114 pp. 89 illustrations. 15s. 0d. net.

The past twenty-five years has seen a remarkable change in the attitude of engineers and other users of materials to the materials they use, and also of the materials they choose.

The absence of methods of finding out the exact behaviour of materials under various forms of stress has for many years confined the engineer to the use of those materials which he could test under certain forms of loading and upon whose unvarying properties he could reasonably rely.

Two things have happened in these past twenty years which have begun that astonishing change in the use of materials and in the materials used in bringing new forms of structure into being. Not a little of those changes now taking place with increasing speed is due to the demands made by the aircraft and aero-engine designer for lighter and stronger materials. The book under review gives a considerable number of references covering a wide range, and it is not without significance that the first reference is to Redshaw's paper on the Electrical Measurement of Strain, published in the JOURNAL of the Royal Aeronautical Society in August 1946.

It was and is largely due to the aircraft designer that the rapid increase in the use of electric resistance strain gauges has taken place. On both sides of the Atlantic there has been a considerable amount of material published and the authors have done a great service by collecting and collating this material.

It is in the practical application of strain gauges to determine what may be termed the residual stress, that these electrical methods are proving of such value. With their aid it is possible to examine the effects of forging, heat treatment, welding, shot blasting, carburising, nitriding, grinding, and so on. Another remarkable use of the strain gauge is as a highly sensitive and precise weight measuring device with a degree of accuracy greater than most of the more usual methods.

The use of the strain gauge for recording stress under flying conditions gives the designer a far better picture of what is happening than he can obtain in any other way. Full-scale flight testing has, indeed, taken on another meaning, for what is happening in any part of the aircraft can be recorded by remote reading gauges, gauges which are light, small and robust.

A book which is fully recommended.

Contents: Chapter I. Gauge Characteristics; Chapter II. Determination of Static Strains; Chapter III. Stress Analysis; Chapter IV. Elementary Electronics; Chapter V. Electronic Bridge Circuits; Chapter VI. Problems in Measuring Dynamic Strain; Chapter VII. Applications of Strain Gauges; Chapter VIII. Brittle Lacquer Method of Stress Estimation.

**Weather Forecasting.** Instructor Commander S. W. C. Pack, R.N. Longmans, Green and Co. Ltd. 1948. 192 pp. Illustrated by diagrams, charts and photographs. 25s. 0d.

How very optimistic the weather experts are! The very titles of their books indicate their optimism to a high degree. *Weather Forecasting*, it will be noted. Not *The Theory and Practice of Weather Forecasting*, or some other title which might indicate a doubt or a difficulty about weather forecasting.

Mark Twain in a famous speech before the New England Society remarked "Probable nor'east to sou'west winds, varying to the southard and westard and eastard and points between; high and low barometer, sweeping round from place to place; probable areas of rain, snow, hail, and drought, succeeded or preceded by earthquakes with thunder and lightning," and in doing so must have had a mental vision of the weather forecasts which start the day in an uneasy frame of mind to so many listeners in this country.

The great peculiarity about the British weather is that it is far finer for people who have just come back from holiday than it is for those just about to go on holiday, much as it is better where you are not than where you are. Most weather broadcasts fit the country as a whole, but not the parts.

The author was Chief Naval Meteorological Officer on the East Indies Station for a time and has had a wide experience of forecasting, for which he says "years of practical experience are required." One almost added "in all weathers"!

In Chapter II the author sums up most adequately what is involved in weather forecasting, and in the remaining chapters deals in a practical and elementary way with the various features which help one to forecast it.

Every man likes to look at his local hill or some familiar landmark, take a quick glance at the sky, note the haze over the nearby gas works, and then announce firmly that despite the cloud it will clear up and there is no need for him to carry a mackintosh. When he comes home soaked I recommend him to buy the book under review. Its general exposition in terms understandable to the amateur meteorologist of the necessary things to know and do will benefit him more than views he might have on the local hill and weather.

*Weather Forecasting* is beautifully produced and the diagrams and illustrations and charts are brilliant examples of how they should be done.

Instructor Commander Pack's book will be invaluable to students and all those who are called upon to have a knowledge of the weather.

One cannot refrain from quoting his remarks on low pressure conditions: "When a complex low pressure system is present it is most difficult to predict with accuracy for more than a few hours ahead what the movement and development of the component parts of the system will be. Indeed there are times when it is quite difficult to explain the weather that has already happened."

Open confession is good on the whole for weather forecasters!

One may finish with an apt quotation from another famous American, Walt Mason:

> "The statesman throws his shoulders back, and straightens out his tie,
> "And says 'My friends, unless it rains, the weather will be dry.'
> "And when this thought into our brains has percolated through,
> "We common people nod our heads and loudly cry 'How true!' "

Or should this have been a review of a political forecast!

**The New Book of Flight.** Edited by C. H. Gibbs-Smith. Geoffrey Cumberlege, Oxford University Press. 1948. 15/- net.

For those who want to buy this book this is the kind of book they will want to buy for the young of their friends, or their own young who look to the air for their rising hopes of their future. It is indeed intended to encourage the young to be air minded and to give them information of possible careers in the air world.

The choice of material for omnibus books of any kind must necessarily be in the hands of the editor. In *The New Book of Flight* Mr. Gibbs-Smith has commissioned articles on as wide a range as possible, from the first one on Rocketry to the last on Air Stamps of the Empire. The appeal is to all tastes and with so many shots at the youthful target from so many angles and distances, the editor is bound to score.

"I hope that the aeronautical students who read this excellent volume" says Sir Frederick Handley Page in an Introduction, "will be inspired by the fine heritage of the British Aircraft Industry."

The reviewer hopes so, too. He hopes, too, that in a book which claims to have assembled together the finest collection of aeronautical photographs in one volume he will include, in a future edition, that hackneyed but historic photograph of the first flight on 17th December 1903 by the Wright brothers. It would be more accurate than the incorrect drawing on page 111 of the event.

One expects good printing and good presentation from the Oxford University Press, and this book lives up to the fine heritage of the British Printing Industry.

Contents:—Rocketry by D. C. Smith; Jet-Propulsion and the Gas Turbine by James Hodge; Helicopter Story by B. J. Hurren; Airships by Lord Ventry; Radar in Aviation by Squadron Leader George Lace, D.F.C.; Flight Refuelling by John Stroud; Pioneers whom I have known by C. G. Grey; The British Empire's Contribution to Aviation by E. Colston Shepherd; British Air Transport by John Stroud; Careers in the R.A.F. by Ross Wilson; Naval Flying as a Career by a Member of the Admiralty; Careers in the British Aircraft Industry by E. C. Bowyer; The Royal Aeronautical Society, Its Work and Activities by Captain J. Laurence Pritchard; Aeromodelling by D. A. Russell; Air Stamps of the Empire by Arthur Blair; Reference Section: Chronology of Aeronautics; the World's Aircraft; Books and Periodicals; The Literature of Flight.

# CORRESPONDENCE

## EQUILIBRIUM RUNNING OF THE SIMPLE JET TURBINE

In the Paper "Equilibrium Running of the Simple Jet Turbine Engine" by A. W. Morley in the May 1948 JOURNAL, the author tries to fulfil by certain tests the three conditions as to continuity of the mass-flow, equilibrium of performances and equality of rotational speed corresponding to the equilibrium running. This time-consuming testing, however, can be easily avoided as proved by the author of this letter in his Paper, published in the magazine "Technique et Science Aéronautiques," volume 1948, No. 1. From the three above-mentioned conditions for the equilibrium running, the three following equations can be derived:

$$[C_P\,(T_{2t}-T_{1t})/N_c^2] = K_1\,.\,[C_P\,(T_{3t}-T_{4t})/N_T^2] \quad . \quad . \quad . \quad (1)$$

$$(Q_c\sqrt{T_{1t}}/P_{1t})\,(N_c/\sqrt{T_{1t}})(P_{1t}/P_{3t}) = K_2\,.\,[Q_T\sqrt{T_{3t}}/P_{3t})\,(N_T/\sqrt{T_{3t}})] \quad . \quad (2)$$

$$(N_c/\sqrt{T_{1t}}) = K_3\,(N_T/\sqrt{T_{3t}})\,.\,\sqrt{T_{3t}}/T_{1t} \quad . \quad . \quad . \quad (3)$$

The constants $K_1$, $K_2$, $K_3$ are hereby to take into consideration the taking off of cooling air, power for auxiliary drives, unequal reference diameters on the compressor (Index C) and on the turbine (Index T) etc. When using the field of characteristics of the compressor as follows:—

Ordinate: $C_P\,.\,(T_{2t}-T_{1t})/N_c^2$

Abscissa: $(Q_c\sqrt{T_{1t}}/P_{1t})\,(N_c/\sqrt{T_{1t}})\,(P_{1t}/P_{3t})$

Parameter: $N_c/\sqrt{T_{1t}}$

and the field of characteristics of the turbine in the following form:—

Ordinate: $K_1\,.\,[C_p\,(T_{3t}-T_{4t})/N_T^2]$

Abscissa: $K_2\,.\,(Q_T\sqrt{T_{3t}}/P_{3t})\,(N_T/\sqrt{T_{3t}})$

Parameter: $K_3\,(N_T/\sqrt{T_{3t}})$

and when superimposing these two fields of characteristics, drawn in the same scales, there will correspond to each point of these superimposed fields a possible state of equilibrium of the compressor-turbine aggregate if to $T_{3t}/T_{1t}$ will be given the value calculated according to the above-mentioned equation (3) from the parameters of the two fields of characteristics. In this case, only those parameters of the field of characteristics of the compressor and turbine can be combined which give the required $T_{3t}/T_{1t}$.

**Dr. H. Hausenblas,** Aeroplanes G. Voisin, Groupe O, Decize/Nievre.

## MR. MORLEY'S REPLY

Dr. Hausenblas gives an alternative set of the three equations necessary for combining the turbine and compressor characteristics of a turbo-jet engine running under equilibrium conditions. These have the merit that when the turbine and compressor curves are plotted with the ordinates and abscissæ suggested, the first two equations are automatically satisfied at all points of intersection when the two sets of curves are superimposed.

In order to satisfy the third equation the particular intersections having the required value of $T_{3t}/T_{1t}$ must be found. On the face of it this does not seem any more difficult than the author's trial and error method.

In an actual case, where the turbine characteristics are not accurately known, Dr. Hausenblas' method would seem to simplify the arithmetic work; so that the time spent would be more in keeping with the accuracy expected. The proposed method of plotting the compressor characteristics also has the advantage that the constant $N_c/\sqrt{T_{1t}}$ curves are brought close together. It does however mean extra work in the preparation of the basic curves.

The method given in the Paper becomes quite simple in practice; and the standard compressor curves of $P_{2t}/P_{1t}$ and $T_{2t}/T_{1t}$ against $N_c/\sqrt{T_{1t}}$ as parameter on a base of $Q\sqrt{T_{1t}}/P_{1t}$ are very suitable for tracing the movement of the operating point with change of $T_{3t}/T_{1t}$ and flight condition. This makes it easier to understand the variation of engine performance, as compared with the more involved plotting used by Dr. Hausenblas.

**A. W. Morley,** *Associate Fellow.*

## SOME ECONOMIC FACTORS IN CIVIL AVIATION

In copying out the final draft of my comments on Mr. Masefield's paper "Some Economic Factors in Civil Aviation" (page 817 of the December 1948 JOURNAL) I carelessly wrote "passenger miles" instead of "passenger hours" at the end of the second paragraph.

Although this error in transcription should have been evident to anyone who had read the previous text, I should like to take this opportunity of making the necessary correction.

My point was that an hour spent airborne by scheduled airline is still about fifty times more likely to end in sudden death than is the same time spent in a train or bus and, until more of us realise this and refuse to accept the fatalities per passenger mile as a basis of comparison with other means of transport, safety will not get that margin of priority over performance which it deserves in civil aviation.

The aeronautical engineers and the airline operators must not rest content until air transport is safe measured by the life assurance companies' yardstick—and that means, of course, until a day spent in a civil air liner is as safe as a day spent in a train or bus. We are a long way yet from that goal, but we must not take our eyes from it just because the journey there is likely to be long and difficult.

**S. B. Bailey,** *Associate Fellow.*

## AIRCRAFT SERVICING AND MAINTENANCE

A system of servicing as suggested in the paper by J. Norman and S. F. Wilkinson (November 1948 JOURNAL) would undoubtedly be a long overdue step in the right direction.

Each component making up an assembly has its own particular maximum life between overhauls and only by concentrating upon improved design and materials in order to lengthen the life of the weakest component can the overhaul life of the assembly be improved. Too often replacement and repair is necessary because of the great disparity between the period of service given by the various components in an assembly, *e.g.*, valves, valve seatings, springs, seals and diaphragms are often comparatively weak members of an otherwise robust assembly.

It is usually failure of an unpredictable nature that causes damage and, although the maximum overhaul life granted to a component or assembly under the proposed system may apply generally, the standard of inspection and assembly after overhaul should be maintained at a high level to eliminate chances of the dangerous exception.

It would appear that the longer the period between overhaul, the more rigid must be the inspection when this period expires.

It is generally agreed, I think, that a standardised screw-thread would do much to obviate maintenance troubles in the field and I believe that a much closer liaison

between manufacturer and operator would result in improvements both in interchangeability and maintenance problems.

The points raised by W. J. Halland (November 1948 JOURNAL) are undoubtedly of importance, both as regards economy and ease of maintenance. I hope he will forgive me if I gleefully anticipate the sight of the "heavies" of the future "bouncing-off" from a "sprung-runway" or landing gracefully at Heathrow on farm-cart wheels. It may be that passengers will demand oleo-suspended seats in such an event.

**Douglas D. Jones,** *Associate.*

It has always been my opinion that if a fraction of the money spent on pure research work in the Aircraft Industry were diverted to the problems of maintenance design, the results would be well worth while.

At the present time there does not appear to be any standardised scientific method of obtaining the practical life of an aircraft component. Individual guesswork tends to produce figures which vary considerably and are not satisfactory for real planning purposes. I agree that a central research organisation is required to which the individual firms could send their products for maintenance life determination.

The Americans, with their climatic hangar, have the right idea, but, so far as I know, there is nothing so ambitious in this country. It is also possible that the Aircraft Industry could learn a few lessons from the car industry, *i.e.*, the methods used to test complete cars and the various accessories.

As a suggestion to improve the maintenance design of components I would like to see the manufacturers give a guaranteed life with free replacements should the items go unserviceable before the time quoted. If a manufacturer were prepared to offer such a guarantee I am sure that his products would be in good demand and that private owners, civil airlines and military air forces would benefit.

Faulty seals, whether they be for oil, petrol, coolant, pneumatic or hydraulic systems, cause a tremendous amount of unserviceability, and any research by a central authority that could improve the present situation would be welcomed by all ground engineers. Surely it is possible to design and produce hydraulic components, whether they be jacks, flow control valves (one of the worst offenders) and the like, which will not require replacing at irregular intervals. Often it is necessary to change items after a couple of flights, making it almost impossible to forecast future store requirements or to maintain adequate stocks.

Any influence that can be used as regards the setting up of some advisory committee dealing with maintenance problems and their solution, I feel, would be of great value to the Aircraft Industry.

**Lieut. (A) A/E. T. E. G. Bowden, R.N.,** *Associate Fellow.*

It is fitting that a paper on "Aircraft Servicing" (November 1948 JOURNAL) should follow soon after one on Aircraft Accidents (July 1948 JOURNAL). Servicing, after all, is done to prevent defects and prevention of defects is another way of saying prevention of accidents.

The larger and, therefore, more complex an aircraft becomes, the greater the chance of any one item of equipment failing in any one flight. It is, therefore, logical and indeed essential for a maintenance schedule to be based on the statistical evidence of defects. Although this could not be applied fully to a new type aircraft just out of prototype stage, many items of standard equipment should have known defect histories. It does not follow, of course, that such parts will necessarily suffer from the same defects if fitted to a different type of aircraft.

The crucial and weakest point is, where do we find comprehensive defect statistics? The ideal is for every manufacturer and operator to have a clear statistical picture of what goes wrong with a part; how often; after how many flying hours and how serious is the failure as a potential or actual cause of an accident (including forced landings). Such knowledge would determine priorities of modifications and the period for inspections and replacements. But this has yet to be accomplished.

The authors of the paper mention four methods for determining the safe life—*i.e.* (*a*) by laboratory research; (*b*) by intelligent guesswork; (*c*) by accurate design for maintenance; (*d*) by operating experience. Considering the thousands and thousands of defect reports rendered during the war, if these reports were collated scientifically, we should be well on the way now to undertake (*b*) with less guesswork. Regarding the recording of the consumption of spares, it is hoped that, in time, items returned to stores will consist solely of those reaching overhaul life and not those which have failed in flight. A comprehensive analysis of defects, however, is essential to determining what is a safe, or reasonably safe life. Such an analysis should cover the widest possible field and, therefore, it would appear necessary to have this undertaken by a central organisation.

**F. A. Baker,** *Associate.*

Much has been written and spoken on the subject of aircraft maintenance, and yet not enough. Each one of us parades his problems and makes suggestions. Some count the cost and others the time wastage, according to their particular function, but all agree that " they " should do something about it if we hope to keep British aircraft to the fore.

Is it not logical that if it takes the combined efforts of the designer, customer, ground engineer and pilot to design, manufacture, service and fly the aircraft, it is only that same combination which can simplify maintenance for both safety and economy?

Mr. Halland believes the solution lies in deleting the need for maintenance. If he means that there should be no immediate servicing or repair of faulty accessories and equipment, but that all faulty parts should be replaced, then I agree, but this represents only a fraction of our troubles.

It would be as well to reflect on ancient and modern design specifications. In the old days one could kick a machine for its " daily " and if it didn't fall to pieces, it was airworthy. Nowadays, it may take several man-hours to correct the setting of ailerons which are super-sensitive to gap. Performance requirements influence design and design influences maintenance.

The poor designer is blamed for not " designing for maintenance," but often the aircraft which goes into service barely resembles the one which the designer viewed on the board some years before. During the war I knew of at least one aircraft which had an all-up weight of 11,000 lb. at birth and went into service at 16,000 lb. One cannot talk of designing for maintenance when a new type can go into service with 300 modifications.

Another point is the number of basic military aircraft which were compelled by the war to carry the burden for civil aviation. Maintenance problems must be greatest on these aircraft which, in their Mk.1 form, were on the drawing board several years ago.

It appears that military and civil aircraft are not parallel cases for consideration and that civil types offer the easier approach for experiment, provided that they are designed purely for civil use.

My own experience of maintenance and its attendant problems is limited to military aircraft and it has taught me that two important factors which would benefit from a little streamlining are ever-changing operational requirements, and technical publications. Publications, being the medium between the designer and the ground engineer, must have considerable influence on the number of " hangar hours." During the war the aim was to provide all necessary maintenance literature concurrently with the delivery of the aircraft. In actual fact, a ground engineer was overcome with emotion if he got it within three months.

Under the existing system of presentation, namely, the three-volume scheme, the ground engineer must make reference to three separate publications in order to fulfil his duties. The Inspection Schedule (Vol. II, Part 2) tells him what to do, the Servicing Manual (Vol. I) how to do it, and the Repair Schedule (Vol. II, Part 3) the limited local repairs that he is permitted to do.

Each publication was written by an M.O.S. author who was presumably an expert on his particular subject. In the case of the Servicing Manual the chapter on maintenance was not issued generally until the Leading Particulars, Pilot's Controls and Equipment, Crew's Controls and Equipment, Loading and C.G. Data, and Ground Handling and Preparation for Flight data had been issued. Then again, the printing of one chapter on maintenance that I know of, covered a period of three months. It all meant that the ground engineer had to find things out for himself, which took time. When he finally received his publication it gave him his control settings in degrees or linear travel to two places of decimals or told him that " the C.G. datum was 74 inches above the ground with the tyres correctly inflated."

Even so, the ground personnel are likely to look back on these things as the " good old days." A re-shuffle has taken place and one author is expected to write the Aircraft Servicing Manual, the Power Plant Manual and the Aircraft Repair Schedule. Considering the variety of subjects encompassed by this work an author would lay no claim to being an expert if he were trained from birth.

If all maintenance data were bound in one volume, each subject covered by an expert in that subject, and issued to the service in good time, it would contribute in a large measure to better maintenance.

**E. Bade,** *Associate.*

The paper " Aircraft Servicing " indicates that a step is being thought out in the right direction for the servicing of aircraft and the new conception on the lines suggested is considered worthy of adoption for all aircraft.

Many aircraft assemblies and accessories appear in repair works which would have given many hours further reliable service before dismantling for repair.

At the end of the recent war, Air Commodore F. R. Banks, I believe, advocated the time factor for engine accessories to 750-1,000 hours for Transport Command York aircraft and my experience of the condition of these after an average of 750 hours was approximately 10 per cent. total scrap; tests on the 90 per cent. satisfactory accessories revealed excellent performance within specification limits and at strip inspection the chief renewable items were ball races.

The flying hours system is coupled with good inspection and testing at the manufacturer's or repair works where, if the inspection sees that parts are within drawing limits, no burrs left on edges, parts have a good finish and are scrupulously clean on assembly, and ensures that correct heat treatment of parts has been carried out and so on, items such as pins, assemblies and accessories will usually give long service without being disturbed.

Operational service reveals all types of defects not obtainable by other means and this is where the basic life of parts would appear to be assessed best, but laboratory tests would be essential, because of various problems which would arise from time to time.

No doubt British aircraft designers would welcome the new conception if it were put into practice as there are many components and assemblies which would give longer, reliable service without being disturbed and more confidence would be instilled in everyone connected with the Industry.

**H. C. Bevis,** *Associate.*

# an appreciation

THE COUNCIL OF THE ROYAL AERONAUTICAL SOCIETY WISH TO THANK THOSE COMPANIES WHO, BY THEIR GENEROUS CO-OPERATION, HAVE DONE SO MUCH TO HELP IN THE PRODUCTION OF THE JOURNAL

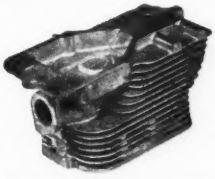

ACCLES & POLLOCK LIMITED

A&P
Make it with Tubes

AIRWORK LIMITED

AIRWORK
LIMITED

AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD.



ALUMINIUM GRAVITY DIE CAST CYLINDER HEAD

ALVIS LIMITED

ALVIS

AIRCRAFT MATERIALS LIMITED

AML
STRUCTURAL MATERIALS
and COMPONENTS

ARMSTRONG SIDDELEY MOTORS LTD.

ARMSTRONG
SIDDELEY

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD

SIR W. G.
ARMSTRONG WHITWORTH
AIRCRAFT LIMITED

BOULTON PAUL AIRCRAFT LTD

BPA

AUTOMOTIVE PRODUCTS COMPANY LTD.

ALL-BRITISH
Lockheed
hydraulics

THE BRISTOL AEROPLANE CO., LTD.

"Bristol"

BIRMINGHAM ALUMINIUM CASTING (1903) CO. LTD.

BIRMAL

THE BRITISH ALUMINIUM CO. LTD.

BA

BLACKBURN AIRCRAFT LTD.

Blackburn
AIRCRAFT

THE BRITISH AVIATION INSURANCE CO. LTD

THE
BRITISH AVIATION
INSURANCE COMPANY LIMITED
3-4 LIME STREET · LONDON · E.C.3
*Phone:* MANsion Hse. 0444 *Grams:* Aviacoy, Lime, London

JAMES BOOTH & COMPANY LTD.

BOOTH
BIRMINGHAM
DURALUMIN
REGISTERED TRADE MARK

BROOM & WADE LTD.

"BROOMWADE"
AIR COMPRESSORS
AND PNEUMATIC TOOLS

DOWTY EQUIPMENT LIMITED

DOWTY
UNDERCARRIAGE AND
HYDRAULIC EQUIPMENT

FOLLAND AIRCRAFT LIMITED

FOLLAND AIRCRAFT LTD.
HAMBLE, SOUTHAMPTON

DUNFORD & ELLIOTT (SHEFFIELD) LTD.

Dunelt
Special steels
FOR AIRCRAFT

GLOSTER AIRCRAFT CO., LTD.

GLOSTER AIRCRAFT CO. LTD.

DUNLOP RUBBER CO., LTD.

DUNLOP

HANDLEY PAGE LIMITED

HP

ENGLISH STEEL CORPORATION LTD.

STEEL MANUFACTURERS
ESC
ENGLISH STEEL
CORPORATION LTD
SHEFFIELD

HAWKER AIRCRAFT LIMITED

HAWKER

THE FAIREY AVIATION COMPANY LTD.

ROTARY WING AIRCRAFT
FAIREY
THE FAIREY AVIATION COMPANY LIMITED

THE HESTON AIRCRAFT CO., LTD.

HESTON AIRCRAFT

H. M. HOBSON LTD.

**Hobson**

INTEGRAL LIMITED

INTEGRAL
HYDRAULIC PUMPS AND EQUIPMENT

F. A. HUGHES & CO., LIMITED

Distributors of
ELEKTRON
REGISTERED TRADE MARK
MAGNESIUM ALLOYS

IRVING AIR CHUTE OF GREAT BRITAIN LTD.

AIR CHUTES
IRVIN

HENRY HUGHES & SON LTD.

REGISTERED TRADE MARK
HUSUN
HENRY HUGHES & SON LTD LONDON

K.L.G. SPARKING PLUGS LTD.

K·L·G
SPARKING PLUGS AND IGNITION EQUIPMENT

THE HUGHES-JOHNSON STAMPINGS LTD.

JH

KELVIN BOTTOMLEY & BAIRD LTD.

KBB

IMPERIAL CHEMICAL INDUSTRIES LTD.
(METALS DIVISION)

ICI

LIGHT-METAL FORGINGS LTD.

LM
F

LODGE PLUGS LIMITED

**LODGE**
**PLUGS**

PERCIVAL AIRCRAFT LIMITED

THE MOND NICKEL COMPANY LTD.

**NICKEL**

PETO & RADFORD

**DAGENITE**
**AIRCRAFT BATTERIES**

D. NAPIER & SON LIMITED

THE PULSOMETER ENGINEERING CO. LTD.

NORMALAIR LIMITED

NORMALAIR

QANTAS EMPIRE AIRWAYS

THE PALMER TYRE LIMITED

*'First in the Air'*

**Palmer**

THE PALMER TYRE LIMITED
Herga House, Vincent Square, London, S.W.1.

A. V. ROE & COMPANY LIMITED

ROLLS-ROYCE LIMITED

ROLLS-ROYCE
AERO-ENGINES

SERCK RADIATORS LIMITED

SERCK

ROTAX LIMITED

ROTAX
AIRCRAFT ELECTRICAL ENGINEERS

SHORT BROTHERS & HARLAND LIMITED

Shorts
Established 1908
THE FIRST MANUFACTURERS
OF AIRCRAFT IN THE WORLD

ROTOL LIMITED

ROTOL

SKYHI LIMITED

SKYHI

SANGAMO WESTON LTD.

AIRCRAFT
Weston †
INSTRUMENTS

SMITHS AIRCRAFT INSTRUMENTS LTD.

SMITHS

SAUNDERS-ROE LIMITED

SARO

THE SPERRY GYROSCOPE COMPANY LTD.

SPERRY

THE TECHNOLOGICAL INSTITUTE OF GREAT BRITAIN

COURSES FOR THE EXAMINATIONS OF THE ROYAL AERONAUTICAL SOCIETY

A. C. WICKMAN LIMITED

A.C. Wickman LIMITED

COVENTRY • ENGLAND •

SPECIALISTS IN MACHINE TOOLS & SMALL TOOLS FOR THE AIRCRAFT INDUSTRY

THE UNITED STEEL COMPANIES LIMITED

"FLYING FOX" ELECTRIC STEELS

S. FOX & CO. LTD. SHEFFIELD

HENRY WIGGIN & COMPANY LTD.

*For High Quality*

NICKEL ALLOYS

VOKES LIMITED

AMBER CROSS

TRADE MARK

SYMBOL OF THE VOKES SERVICE

WILLIAMSON MANUFACTURING CO., LTD.

WESTLAND AIRCRAFT LIMITED

WESTLAND AIRCRAFT LIMITED

Yeovil, Somerset

YORKSHIRE ENGINEERING SUPPLIES LTD.

BRONZE FOUNDRIES

YESEATONIA

BEARINGS AND BUSHES

**The Journal is published monthly at the Offices of the Society, 4 Hamilton Place, Piccadilly, London, W1.** None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case. Subscriptions per annum, £4 13 0 including postage; Single Numbers 7/6 or 7/9 post free. All communications for publication or Advertisements in the Journal, or on general matters affecting the Society should be addressed to—The Secretary, J. Laurence Pritchard, 4 Hamilton Place, W1. The Society's Bankers are Messrs. Coutts & Co.

Telephone: Grosvenor 3515 (5 lines) Telegraphic Address: Didaskalos, Audley, London.

# DIRECTORY OF ADVERTISERS

| | | |
|---|---|---|
| ACCLES & POLLOCK LTD. | Paddock Works, Oldbury, Birmingham | Broadwell 1500 |
| AEROPLANE & MOTOR ALUMINIUM CASTINGS LTD. | Wood Lane, Erdington, Birmingham | Erdington 2207-9 |
| AIRCRAFT MATERIALS LTD. | Midland Road, London, N.W.1 | Euston 6151 |
| AIRSPEED LTD. | The Airport, Portsmouth | Portsmouth 74631 |
| AIRWORK LTD. | 15 Chesterfield Street, London, W.1 | Grosvenor 4841 |
| ALVIS LTD. | Holyhead Road, Coventry | Coventry 5501 |
| ANGLO-AMERICAN OIL CO. LTD. | Artillery House, London, S.W.1 | Abbey 4882 |
| ARMSTRONG SIDDELEY MOTORS LTD. | Parkside, Coventry | Coventry 4061 |
| ARMSTRONG WHITWORTH AIRCRAFT, SIR W. G., LTD. | Whitley, Coventry | Coventry 61061-4 |
| AUTOMATIC COIL WINDER & ELECTRICAL EQUIPMENT CO. LTD. | Winder House, Douglas Street, London, S.W.1 | Victoria 3404-8 |
| AUTOMOTIVE PRODUCTS CO. LTD. | Tachbrook Road, Leamington Spa | Leamington Spa 1700 |
| BIRMINGHAM ALUMINIUM CASTING (1903) CO. LTD. | Birmid Works, Smethwick, Birmingham, 40 | Smethwick 1431 |
| BLACKBURN AIRCRAFT LTD. | Brough, E. Yorks. | Brough 121 |
| BOOTH, JAMES & CO. LTD. | Argyle Street Works, Nechells, Birmingham, 7 | Birmingham E. 1221 |
| BOULTON PAUL AIRCRAFT LTD. | Wolverhampton, Staffs. | Fordhouses 3191 |
| BRISTOL AEROPLANE CO. LTD., THE | Filton House, Bristol | Bristol 48051 |
| BRITISH ALUMINIUM CO. LTD. | Salisbury House, London Wall, E.C.2 | Clerkenwell 3494 |
| BRITISH AVIATION INSURANCE CO. LTD. | 3/4 Lime Street, London, E.C.3 | Mansion House 0444 |
| BRITISH BELTING AND ASBESTOS LTD. | Cleckheaton, Yorks. | Cleckheaton 800 |
| BRITISH MESSIER LTD. | 59 Southwark Street, London, S.E.1 | Hop. 0192 |
| BRITISH OVERSEAS AIRWAYS CORPORATION | Cheltenham Road East, Gloucester | Churchdown 3281 |
| | Headquarters: Airways House, Berkeley Square, W.1. | Mayfair 8400 |
| | Traffic Enquiries: Airways Terminus, Victoria | Victoria 2323 |
| BRITISH WIRE PRODUCTS LTD. | Worcester Road, Stourport-on-Severn | Stourport 240 |
| BROOM & WADE LTD. | High Wycombe, Bucks. | High Wycombe 1630 |
| DE HAVILLAND AIRCRAFT CO. LTD., THE | Hatfield Aerodrome, Herts. | Hatfield 2345 |
| DELCO-REMY & HYATT LTD. | 111 Grosvenor Road, London, S.W.1. | Victoria 6242 |
| DOWTY EQUIPMENT LTD. | Cheltenham, Gloucester | Cheltenham 53471 |
| DUNFORD & ELLIOTT (SHEFFIELD) LTD. | Attercliffe Wharf Works, Sheffield, 9 | Sheffield 41121-4 |
| DUNLOP RUBBER CO. LTD. | Fort Dunlop, Erdington, Birmingham, 24 | Erdington 2121 |
| ENGLISH STEEL CORPORATION LTD. | Vickers Works, Sheffield | Sheffield 41071 |
| FAIREY AVIATION CO. LTD. | Hayes, Middlesex | Hayes 3800 |
| FIRTH-VICKERS STAINLESS STEELS LTD. | Staybrite Works, Sheffield | Sheffield 41193 |
| FOLLAND AIRCRAFT LTD. | Hamble, Southampton, Hants. | Hamble 3191 |
| GENERAL AIRCRAFT LTD. | The London Air Park, Feltham, Middlesex | Feltham 3636 |
| GLOSTER AIRCRAFT CO. LTD. | Gloster Works and Aerodrome, Hucclecote, Glos. | Gloucester 66294 |
| GRAVINER MANUFACTURING CO. LTD. | (Aircraft Division Sales Dept.). Poyle Mill Works, Colnbrook, Bucks. | Colnbrook 48-49 |
| HANDLEY PAGE LTD. | Cricklewood, London, N.W.2 | Gladstone 8000 |
| HAWKER AIRCRAFT LTD. | Canbury Park Road, Kingston-on-Thames | Kingston 1044 |
| HESTON AIRCRAFT CO. LTD., THE | Heston Airport, Middlesex | Southall 2321 |
| HOBSON, H. M., LTD. | Hobson Works, Fordhouses, Wolverhampton | Fordhouses 2266 |
| HUGHES, F. A., & CO. LTD. | Bath House, 82 Piccadilly, London, W.1 | Grosvenor 6300 |
| HUGHES, HENRY & SON LTD. | Husun Works, New North Road, Barkingside, Essex | Hainault 2601 |
| HUGHES-JOHNSON STAMPINGS LTD., THE | Langley Green, Birmingham | Broadwell 1361 |
| ILIFFE AND SONS LTD. | Dorset House, Stamford Street, London, S.E.1 | Waterloo 3333 |
| IMPERIAL CHEMICAL INDUSTRIES LTD. (METALS DIVISION) | Kynoch Works, Witton, Birmingham, 6 | Birchfield 4848 |
| INTEGRAL LTD. | Cousins Street, Dudley Road, Wolverhampton | Wolverhampton 24984 |
| IRVING AIR CHUTE OF GREAT BRITAIN LTD. | Ickneild Way, Letchworth, Herts. | Letchworth 888 |
| K.L.G. SPARKING PLUGS LTD. | Putney Vale, London, S.W.15 | Putney 2671 |
| KELVIN, BOTTOMLEY & BAIRD LTD. | Kelvin Avenue, Hillingdon, Glasgow, S.W.2 | Halfway 3331 |
| | Kelvin Works, Basingstoke | Basingstoke 690 |
| LIGHT-METAL FORGINGS LTD. | Oldbury, Birmingham | Broadwell 1152 |
| LODGE PLUGS LTD. | Rugby | Rugby 2076 |
| MARSTON EXCELSIOR LTD. | Wolverhampton | Wolverhampton 21481 |
| | 49/59 Armley Road, Leeds, 12 | Armley 38081-5 |
| MOLLART ENGINEERING CO. LTD. | Kingston By-Pass, Surbiton, Surrey | Elmbridge 3352-4 |
| MOND NICKEL CO. LTD., THE | Grosvenor House, Park Lane, London, W.1 | Grosvenor 4131 |

# DIRECTORY OF ADVERTISERS

| | | |
|---|---|---|
| NAPIER, D., & SON LTD. | Acton, London, W.3 | Shepherds Bush 1220 |
| NORMALAIR LTD. | West Hendford, Yeovil, Somerset | Yeovil 1100 |
| PALMER TYRE LTD., THE | Herga House, Vincent Square, London, S.W.1 | Victoria 8323 |
| PERCIVAL AIRCRAFT LTD. | Luton Airport, Luton, Beds. | Luton 2960 |
| PETO & RADFORD | Chequers Lane, Dagenham, Essex | Rainham 34 |
| PITMAN, SIR ISAAC & SONS LTD. | Parker Street, Kingsway, London, W.C.2 | Holborn 9791 |
| PULSOMETER ENGINEERING CO. LTD., THE | Nine Elms Iron Works, Reading. 39 Victoria Street, London, S.W.1 | Tilehurst 67182-4 |
| QANTAS EMPIRE AIRWAYS | c/o British Overseas Airways Corporation, Airways Terminus, Buckingham Palace Road, S.W.1 | Victoria 3126 |
| ROE, A. V., & CO. LTD. | Greengate, Middleton, Manchester | Failsworth 2020-2039 |
| ROLLS-ROYCE LTD. | Derby | Derby 2424 |
| ROTAX LTD. | Willesden Junction, London, N.W.10 | Elgar 7777 |
| ROTOL LTD. | Cheltenham Road, Gloucester | Gloucester 24431 |
| SANGAMO WESTON LTD. | Great Cambridge Road, Enfield, Middlesex | Enfield 3434 & 1242 |
| SAUNDERS-ROE LTD. | 49 Parliament Street, Westminster, S.W.1 | Whitehall 7271 |
| SERCK RADIATORS LTD. | Warwick Road, Birmingham, 11 | Victoria 0531 |
| SHORT BROTHERS AND HARLAND LTD. | Seaplane Works, Queen's Island, Belfast | Belfast 58444 |
| SKYHI LTD. | "Skyhi" Works, Worton Road, Isleworth, Middlesex | Hounslow 2211 |
| SMITHS AIRCRAFT INSTRUMENTS LTD. | Cricklewood Works, London, N.W.3 | Gladstone 3333 |
| SPERRY GYROSCOPE CO. LTD., THE | Great West Road, Brentford, Middlesex | Ealing 6771 |
| TECHNOLOGICAL INSTITUTE OF GREAT BRITAIN LTD., THE | 39 Temple Bar House, Fleet Street, London, E.G.4 | Central 5940 |
| TEMPLE PRESS LTD. | Bowling Green Lane, London, E.C.1 | Terminus 3636 |
| UNITED STEEL COMPANIES LTD., THE | 17 Westbourne Road, Sheffield, 10 | Sheffield 60081 |
| VICKERS-ARMSTRONGS LTD. | Vickers House, Broadway, Westminster, S.W.1 | Abbey 7777 |
| | Weybridge Works, Weybridge, Surrey | Byfleet 240-243 |
| | Supermarine Works, Hursley Park, Winchester, Hants. | Chandlersford 2251 |
| VOKES LTD. | Henley Park, near Guildford, Surrey | Guildford 62861 |
| WAKEFIELD, C. C., & CO. LTD. | 46 Grosvenor Street, London, W.1 | Mayfair 9232 |
| WESTLAND AIRCRAFT LTD. | Yeovil, Somerset | Yeovil 1100 |
| WICKMAN, A. C., LTD. | Tile Hill, Coventry | Tile Hill 66271 |
| WIGGIN, HENRY, & CO. LTD. | Wiggin Street, Birmingham | Edgbaston 2245 |
| WILLIAMSON MANUFACTURING CO. LTD. | Litchfield Gardens, Willesden Green, N.W.10 | Willesden 0073-0075 |
| YORKSHIRE ENGINEERING SUPPLIES LTD. | Bronze Foundries, Upper Wortley Road, Leeds, 12 | Leeds 38234 & 38291 |

THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

# FEBRUARY 1949 NOTICES

## THE CHARTER OF INCORPORATION

The President, Dr. H. Roxbee Cox, and the Council of the Society have very great pleasure in announcing to all members that the Society has been granted a Charter of Incorporation as from the 17th January 1949. The letter below is the formal announcement from His Majesty's Most Honourable Privy Council and is repeated with the full text of the Charter in the pages of the JOURNAL. For those who do not receive the JOURNAL a copy of the Charter is attached to these Notices.

**AT THE COURT AT BUCKINGHAM PALACE**

**The 22nd day of December 1948**

PRESENT

**THE KING'S MOST EXCELLENT MAJESTY**

IN COUNCIL

WHEREAS there was this day read at the Board a Report of a Committee of the Lords of His Majesty's Most Honourable Privy Council, dated the 8th day of December, 1948, in the words following, viz.:—

"YOUR MAJESTY having been pleased, by Your Order of the 2nd day of June, 1948, to refer unto this Committee the humble Petition of H. Roxbee Cox, Esquire, and others, praying for the grant of a Charter of Incorporation to the Royal Aeronautical Society.

"THE LORDS OF THE COMMITTEE, in obedience to Your Majesty's said Order of Reference, have taken the said Petition into consideration, and do this day agree humbly to report, as their opinion, to Your Majesty, that a Charter may be granted by Your Majesty in terms of the Draft hereunto annexed."

HIS MAJESTY having taken into consideration the said Report, and the Draft Charter accompanying it, was pleased, by and with the advice of His Privy Council, to approve thereof, and to order, as it is hereby ordered, that the Right Honourable James Chuter Ede, one of His Majesty's Principal Secretaries of State, do cause a Warrant to be prepared for His Majesty's Royal Signature, for passing under the Great Seal a Charter in conformity with the said Draft, which is hereunto annexed.

*E. C. E. Leadbitter.*

## CONTENTS OF THE FEBRUARY JOURNAL

The Charter of Incorporation.

French Turbo-Propeller and Turbo-Reaction Engines, by P. Destival.

Development of the Armstrong-Siddeley Mamba Engine, by W. H. Lindsey, M.A., A.F.R.Ae.S.

Estimation of Cruising Air Speeds for Economic Analysis, by Alan H. Stratford, B.Sc., A.F.R.Ae.S.

An Airline's Engineering Service Experience and its Use in the Design of Transport Aircraft, by H. S. Crabtree, A.F.R.Ae.S.

Reviews.

Correspondence.

*The Council have set aside an annual sum of £250 for the award of premiums for papers published in the Journal and hope that members (or non-members) will contribute papers on their own special subjects.*

## SPECIAL NOTICE—WILBUR WRIGHT LECTURE

The Thirty-Seventh Wilbur Wright Memorial Lecture to be given by Dr. Hugh Dryden, F.R.Ae.S., Director of Aeronautical Research to the National Advisory Committee of Aeronautics, on "The Aeronautical Research Scene—Goals, Methods and Accomplishments," on Thursday, 28th April 1949, will be held at the *Royal Institution, 21 Albemarle Street, London, W.*1, at 6 p.m. Tea will be served at 5.30.

## ANGLO-AMERICAN AERONAUTICAL CONFERENCE

The following preliminary details of the programme for the Anglo-American Conference to be held in America in May and June 1949 give a general idea of the programme:—

The 23rd May will be an Open Day at the Institute of the Aeronautical Sciences. The technical sessions will be from 24th May to 27th May. The British papers for the technical sessions have been arranged as follows:—

| *Paper* | *Author* |
|---|---|
| The Relative Merits of Auxiliary Power Systems:— | |
| Hydraulic | H. G. Conway |
| Electric | R. H. Woodall |
| Pneumatic | H. R. Haerle |
| Turbine-Engined Transport Aircraft | G. R. Edwards |
| Research on Helicopters at the R.A.E. with special reference to the Stability of Multi-Rotor Helicopters | H. B. Squire |
| Materials from the Designers' Point of View | A. E. Russell |
| Operational Use of Propeller Gas Turbines | F. M. Owner |
| The Application of Materials from the Manufacturers' Point of View | Major P. L. Teed |
| The Relative Efficiencies of Large Landplanes and Flying Boats | D. Keith Lucas |
| The Life of Aircraft Structures | H. A. Wills |
| Some Considerations of the Flutter Problems of High Speed Aircraft | E. G. Broadbent |
| Operating Factors Affecting the Design of Civil Aircraft | C. Dykes |

An equal number of American papers on subjects covering the field of Aeronautics will be included in these sessions.

Following the technical sessions a week of visits to plants and Government Laboratories has been arranged. Among the visits arranged are:—

Langley Memorial Aeronautical Laboratory in Virginia.
The Patuxent Air Station, the Navy's Test Station.
The Naval Aircraft Factory in Philadelphia.
Republic Aviation Corporation.
Grumman Aircraft Engineering Corporation.
Curtiss-Wright Corporation, Engine and Propeller Divisions.

Applications to attend the Conference must be received *not later than* 1*st March* 1949. The Conference will be held in Washington and those attending should make as far as possible their own arrangements for travelling. The Institute of the Aeronautical Sciences have appointed a Committee of their members in Washington to arrange the details of the Conference including accommodation of delegates, visits and so on. Particulars will be announced when they are available.

## NOMINATION OF COUNCIL

The following is an extract from the Rules:—

"The twenty-one ordinary members of Council shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes, Associate Fellow, Associate and Graduate.

"Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since election but they shall be eligible for re-election.

"Nominations of candidates for election to the Council must be received by the Secretary not later than 10*th April* in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be voters.

"Nomination forms may be obtained on application to the Secretary."

## NEW YEAR HONOURS

The following Members were included in the New Year's Honours List:—

*K.G.C.B.* (*Civil*)
Sir Henry Tizard, K.C.B., A.F.C., F.R.S. (Fellow).

*C.B.* (*Military*)
Air Commodore A. W. B. McDonald, A.F.C., B.A. (Associate Fellow).
Major General H. J. Parham, D.S.O. (Companion).

*C.B.E.* (*Civil*)
Major K. M. Beaumont, D.S.O., M.A. (Associate Fellow).
Mr. W. C. Devereux (Fellow).

*O.B.E.*
Mr. H. R. Gillman (Associate Fellow).
Mr. J. Wright (Fellow).

*M.B.E.*
Mr. D. W. Richardson (Associate Fellow).

*Commendation for Valuable Service in the Air*
Lt. Commander E. M. Brown, O.B.E., D.S.C., A.F.C., M.A. (Associate).

## MEMBERS' NEW APPOINTMENTS

Mr. C. P. T. Lipscomb, Wh.Ex., Fellow—Director in Charge of Research and Development, Short Brothers & Harland Ltd.

Mr. D. Keith-Lucas, B.A., Fellow—Chief Designer, Short Brothers & Harland Ltd.

Mr. A. W. S. Clarke, Associate Fellow—Chief Engineer, Short Brothers & Harland Ltd.

Sir Roy Fedden, M.B.E., Fellow—Director of Research and Development on the Board of Leyland Motors.

Captain A. G. Store, B.Sc., A.C.G.I., Associate Fellow—Operations Manager, British South American Airways.

Mr. W. S. McGaw, B.Sc., Associate Fellow—Director of Aircraft Production, Ministry of Supply (correction from January issue).

Mr. J. Calderwood, M.Sc., Associate Fellow—Technical Director, British Oil Engines Ltd.

Dr. S. G. Hooker, O.B.E., Fellow—Assistant to Chief Engineer (Aero-Engine Division), The Bristol Aeroplane Company Ltd.

## INSTITUTE OF THE AERONAUTICAL SCIENCES

The Council of the Institute has announced the following elections:—

To Honorary Fellowship—Professor S. Goldstein, F.R.Ae.S.
—Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

## ASSOCIATE FELLOWSHIP EXAMINATIONS

Candidates are reminded that a new Associate Fellowship Examination syllabus came into force on 1st January 1949, but that papers will continue to be set in the old syllabus up to and including December 1949. Entry forms for the May examination under the old syllabus must be in by 28th February 1949. The closing date for entries for Part I of the new syllabus was 31st January 1949.

## LECTURE PROGRAMME—SPRING 1949

Unless otherwise stated, lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, London, S.W.1 (by permission of the Council of the Institution). Tea will be served at 5.30 p.m.

**Thursday, 10th February 1949**—THE SECOND LOUIS BLERIOT LECTURE: French Practical Aerodynamic Methods, by Monsieur Jean Brocard and Monsieur Francois Hussenot.

**Thursday, 17th February 1949**—Planned Servicing in the Royal Air Force, by Sqdn. Ldr. E. A. Harrop, O.B.E., A.F.R.Ae.S.

**Thursday, 24th February 1949**—Flutter and Stability, by Professor W. J. Duncan, B.Sc., F.R.Ae.S., M.I.Mech.E., F.R.S.

**Saturday, 5th March 1949**—FULL DAY DISCUSSION ON AIR SAFETY.

*Morning Session* 11 *a.m.*—1 *p.m.*

The Theoretical Aspects of Airworthiness and Safety, by J. D. North, F.R.Ae.S.

The Physiological Aspects of Safety, by Dr. K. G. Bergin, M.A., M.D., A.F.R.Ae.S.

**1 p.m.—2.30 p.m.**—Luncheon Interval (Members should make their own arrangements).

*Afternoon Session* 2.30 *p.m.*—4.30 *p.m.*

Safety from the Pilot's View Point, by Captain J. W. G. James, O.B.E.

Operational Research into Air Traffic Control, by Dr. G. E. Bell, M.Sc.

**4.30 p.m.—5 p.m.**—Tea Interval (Tea will be provided at the Lecture Hall).

*Evening Session* 5 *p.m.*—6.30 *p.m.*

General Discussion and summing-up by the Lecturers and the Chairman.

**Thursday, 17th March 1949**—The Design of Propellers, by J. Mullin, B.Sc.(Eng.), A.F.R.Ae.S., and C. G. I. Gardiner.

**Tuesday, 22nd March 1949**—JOINT MEETING WITH THE AIRPORT ENGINEERING DIVISION OF THE INSTITUTION OF CIVIL ENGINEERS.

*Tea at 5 p.m. Lectures at 5.30 p.m.*

Aircraft Design with Special Reference to the Restrictions Imposed by Considerations in Airfield Design, by P. H. Watson, B.Sc., A.F.R.Ae.S.

The Problem of Airfield Design in Relation to Aircraft Design, by C. E. Foster, C.B.E., B.Sc.(Eng.), A.M.I.C.E.

**Thursday, 31st March 1949**—Repeated Loading of Aircraft Structures, by Dr. P. B. Walker, M.A., F.R.Ae.S.

**Thursday, 7th April 1949**—Investigation of Aircraft Accidents in Relation to Aircraft Design, by Air Commodore Vernon Brown, C.B., O.B.E., M.A., F.R.Ae.S.

**Thursday, 21st April 1949**—High Lift Devices and Their Use, by R. R. Duddy, A.F.R.Ae.S. (*At the Portsmouth Municipal College at 7 p.m.*)

**Thursday, 28th April 1949**—THE THIRTY-SEVENTH WILBUR WRIGHT LECTURE:—

The Aeronautical Research Scene—Goals, Methods and Accomplishments, by Dr. Hugh Dryden, F.R.Ae.S., Director of Aeronautical Research to the National Advisory Committee of Aeronautics. (*At the Royal Institution, 21 Albemarle Street, W.1, at 6 p.m.*)

## GRADUATES' AND STUDENTS' SECTION—LECTURE PROGRAMME 1949

**Wednesday, 2nd March 1949**—The Development of the Brabazon I, by G. P. Hebden, A.F.R.Ae.S., Bristol Aeroplane Co. Ltd.

**Wednesday, 23rd March 1949**—Annual General Meeting of the Section.

**Wednesday, 6th April 1949**—The Trend of Jet Engine Development, by A. A. Lombard, A.F.R.Ae.S , Chief Designer (Projects), Rolls-Royce Ltd.

**Tuesday, 19th April 1949**—The Meaning and Measurement of Stability Derivatives, by P. T. Fink, B.E., Grad.R.Ae.S., Imperial College.

**Thursday, 12th May 1949**—Pressure Cabins, by D. Cardwell, B.Sc., A.C.G.I., A.F.R.Ae.S., Royal Aircraft Establishment.

Meetings will be held in the Library of the Royal Aeronautical Society, 4 Hamilton Place, W.1, at 7.30 p.m. *The Library will not be open before 7 p.m.*

### BELFAST BRANCH

**Tuesday, 22nd February 1949**—Three Lecturettes, by Branch Members, followed by an informal discussion.

**Tuesday, 8th March 1949**—Helicopter Design, by T. E. Goligher, B.Sc., D.I.C., A.F.R.Ae.S.

**Tuesday, 22nd March 1949**—A Lecture, by P. G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., G.I.Mech.E. (Title to be announced later.)

**Friday, 8th April 1949**—General Meeting.

Lectures will be held in the Central Hall, College of Technology, Belfast, at 7 p.m.

### BRISTOL BRANCH

**Wednesday, 16th February 1949**—The Physics of the Nucleus, by Professor C. F. Powell, M.A., Ph.D., Melville Wills Professor of Physics, University of Bristol.

**Monday, 7th March 1949**—To be arranged.

**Monday, 28th March 1949**—The organisation of British Aeronautical Research, by H. M. Garner, M.A., F.R.Ae.S., Principal Director of Aircraft Scientific Research, Ministry of Supply, Bristol.

**Monday, 11th April 1949**—The Aeroplane as a Commercial Product, by Captain K. J. G. Bartlett, Sales Director, The Bristol Aeroplane Co. Ltd.

**Monday, 25th April 1949**—Annual General Meeting and Film Show.
Meetings will be held in the Conference Room, Bristol Aeroplane Co. Ltd., Filton House, at 6 p.m.

BROUGH BRANCH

**Wednesday, 16th February 1949**—Jet Engines, by W. T. Winter, The de Havilland Engine Co. Ltd. *At Hull.*

**Wednesday, 16th March 1949**—Supersonic Flight, by J. R. Ewans, B.Sc., D.I.C., A.F.R.Ae.S., B.A. Ltd., Aerodynamics Staff. *At Brough.*

**Wednesday, 13th April 1949**—The Brabazon Aircraft, by F. H. Pollicut, Bristol Aeroplane Co. Ltd. *At Hull.*

Lectures at *Brough* are held at the Flying Club, at 5.45 p.m.
Lectures at *Hull* are held in the Lecture Hall, Electricity Showrooms, Ferensway, at 7.30 p.m.

COVENTRY BRANCH

**Thursday, 17th February 1949**—The London-Sydney Air Route, by C. H. Jackson, B.O.A.C.

**Thursday, 17th March 1949**—The Automatic Pilot, by A. I. O. Davies, Smiths' Aircraft Instruments Ltd.

**Thursday, 28th April 1949**—Annual General Meeting and Film.
All lectures will be held in the Old Gulson Library, Coventry, at 7.30 p.m.

DERBY BRANCH

**Monday, 14th February 1949**—Pictures in the Air, by Charles E. Brown, F.I.B.P., A.R.P.S.

**Monday, 7th March 1949**—Helicopters—The Technical Point of View, by Capt. R. N. Liptrot, C.B.E., B.A.

**Monday, 4th April 1949**—Rocket Propulsion and Inter-Planetary Flight, by A. V. Cleaver, A.R.Ae.S.

**Monday, 2nd May 1949**—Lubrication of Aero Gas Turbines, by J. G. Dawson, B.Sc., A.F.R.Ae.S.

Meetings will be held at the Rolls-Royce Welfare Hall, Nightingale Road, Derby, at 6.15 p.m.

GLOUCESTER AND CHELTENHAM BRANCH

**Wednesday, 16th February 1949**—The Design of an Aeroplane, by Professor R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S. *At Cheltenham.*

**Thursday, 3rd March 1949**—Electrical Aircraft Instruments, by E. B. Moss, B.Sc., F.Inst.P., M.I.Mech.E. *At Gloucester.*

**Wednesday, 30th March 1949**—Radar Aids in Aeronautics, by Dr. S. F. Evans, M.Sc., Ph.D. *At Cheltenham.*

**Thursday, 21st April 1949**—Annual General Meeting. Followed by Film, Atomic Physics. *At Gloucester.*

All meetings are held at 7.30 p.m. unless otherwise notified.

*Gloucester Meetings* (Thursdays) are held in the Wheatstone Hall, City Library, Brunswick Road. *Cheltenham Meetings* (Wednesdays) are held in the Chemistry Lecture Theatre, Grammar School (entrance off Oxford Passage).

HATFIELD BRANCH

**Wednesday, 16th February 1949**—The Probable Role and Influence of Aircraft in Future Warfare, by Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

**Wednesday, 16th March 1949**—Annual General Meeting.
All meetings will be held in the de Havilland Senior Staff Mess, at 6.15 p.m.

## ISLE OF WIGHT BRANCH

**Thursday, 24th February 1949**—Naval Aircraft, by Lieut. Commander E. M. Brown, O.B.E., D.F.C., M.A., A.F.R.Ae.S.

**Thursday, 10th March 1949**—A Lecture, by N. E. Rowe, C.B.E., D.I.C., B.Sc., F.R.Ae.S. (Provisional.)

**Thursday, 24th March 1949**—Brains Trust.

Meetings will be held in the Sports and Social Club, Saunders-Roe Ltd., East Cowes, Isle of Wight, at 6 p.m.

## LEICESTER BRANCH

**Wednesday, 9th February 1949**—Airscrews, by E. Danvers, Rotol Ltd.

**Wednesday, 9th March, 1949**—Charter Flying, by Squadron Leader Wright, Wright Aviation Ltd.

**Wednesday, 23rd March 1949**—Films.

**Wednesday, 13th April 1949**—Annual General Meeting and Members' Papers.

Meetings will be held in Room 104, College of Technology, The Newarkes, Leicester, at 7.15 p.m.

## LUTON BRANCH

**Wednesday, 2nd March 1949**—The Design and Evolution of a Modern Aeroplane, by Professor R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S.

**Wednesday, 23rd March 1949**—Members' Discussion evening.

**Wednesday, 6th April 1949**—Film Show.

At the George Hotel, Luton, at 7.30 p.m.

## MANCHESTER BRANCH

**Thursday, 24th February 1949**—The Development of the Mamba Engine, by A. S. Lindsey, M.A., A.F.R.Ae.S.

**Thursday, 17th March 1949**—Personal Experiences of Early Aerodynamic Research, by Professor Sir B. Melvill Jones, C.B.E., A.F.C., F.R.S., Hon.F.I.Ae.S., F.R.Ae.S.

**Thursday, 28th April 1949**—Rocket Propulsion and Interplanetary Flight, by A. V. Cleaver, A.R.Ae.S.

All lectures will be held in the Reynolds Hall at the College of Technology, Manchester, at 7.30 p.m.

## PORTSMOUTH BRANCH

**Friday, 11th February 1949**—Short papers by members of the Branch.

**Friday, 11th March 1949**—The " Debunking " of Aeronautical Sciences, by C. G. Grey, F.M.R.Ae.S.

All lectures will be held in the Lecture Hall at the Central Library, Guildhall Square, Portsmouth, at 7 p.m.

## PRESTON BRANCH

**Wednesday, 16th February 1949**—The Propeller-Turbine Aero-Engine, by F. H. Owner, M.Sc., F.R.Ae.S., M.S.A.E.

**Wednesday, 9th March 1949**—Recent Developments in Aircraft Production Engineering, by Professor J. V. Connolly, B.E., A.F.R.Ae.S.

**Wednesday, 30th March 1949**—To be arranged.

**Wednesday, 27th April 1949**—Annual General Meeting.

All lectures will be held in the Assembly Hall of the Technical College, Corporation Street, Prestwick, at 7.15 p.m.

SOUTHAMPTON BRANCH

**Wednesday, 9th February 1949**—Radio Aids, by F. R. Wills.

**Tuesday, 8th March 1949**—A Lecture, by A. G. Pugsley, O.B.E., D.S.C.

The lectures will be held in the Physics Lecture Theatre, University College, Southampton, at 7 p.m.

WEYBRIDGE BRANCH

**Wednesday, 9th February 1949**—Civil Air Transport, by P. G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., G.I.Mech.E.

**Wednesday, 9th March 1949**—Air Force Requirements and their Origin, by Air Commodore G. W. Tuttle, C.B., C.B.E., D.F.C., Director of Operational Requirements.

**Wednesday, 6th April 1949**—Historical Review of Aircraft Development, by Sir Frederick Handley Page, C.B.E., F.R.Ae.S.

**Wednesday, 27th April 1949**—Present-Day Problems in Safety Requirements, by W. Tye, O.B.E., B.Sc., F.R.Ae.S., Air Registration Board.

**Wednesday, 18th May 1949**—Junior Prize Lecture, by Branch members.

**Wednesday, 1st June 1949**—General Meeting.

Meetings will be held at Vickers-Armstrongs Ltd., Weybridge Works, at 6 p.m., unless previous notice is given.

## ANNUAL SUBSCRIPTIONS OF MEMBERS

Members are reminded that their annual subscriptions became due on 1st January 1949. The rates are:—

| | Home | Abroad |
|---|---|---|
| | £ s. d. | £ s. d. |
| Fellows | 5 5 0 | 4 4 0 |
| Associate Fellows | 4 4 0 | 3 3 0 |
| Associates | *3 3 0 | *3 3 0 |
| Graduates (aged 21-25) | 2 2 0 | 2 2 0 |
| Graduates (aged 26-28) | 2 12 6 | 2 12 6 |
| Students (aged under 21) | 1 1 0 | 1 1 0 |
| Students (aged 21 and over) | 1 11 6 | 1 11 6 |
| Companions | 3 3 0 | 3 3 0 |
| Founder Members | 2 2 0 | 2 2 0 |

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership.

Remittances should be made payable to either the Royal Aeronautical Society or Aerial Science Ltd.

## JOURNAL BINDING

The new prices of binding of Journals will be as follows:—

| | | |
|---|---|---|
| 1948 Volume | 14s. 6d. | (including packing and postage) |
| Previous Volumes | 16s. 0d. | ,, ,, ,, ,, |
| Cases for 1948 Volume | 6s. 0d. | ,, ,, ,, ,, |

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Requests for cases, with remittances, should be sent to the Secretary at the Offices of the Society.

## CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

## POSTS AT FARNBOROUGH

Applications are invited by the Ministry of Supply for posts in the following grades at the Royal Aircraft Establishment, Farnborough, Hants, for work in connection with the planning of future aircraft projects:—

| | | |
|---|---|---|
| Principal Scientific Officer | .. .. Salary range | £910-£1,177 |
| Senior Scientific Officer | .. .. .. | £670- £860 |
| Scientific Officer | .. .. .. .. | £380- £620 |

Rates for women are somewhat lower.

Candidates should have a good Honours degree, or equivalent, in mathematics, physics, mechanical or aeronautical engineering and have preference for work on broad problems rather than for specialisation. They should have experience in structural or aerodynamics work in connection with design of aircraft or project work.

The appointments are unestablished but carry F.S.S.U. benefits. Opportunities to compete for established posts may occur later.

Write quoting A. 451/48/A to Ministry of Labour and National Service, Technical and Scientific Register (K), York House, Kingsway, London, W.C.2, for *application form which must be returned completed by 28th February* 1949.

## NEW MEMBERS

*Associate Fellows*

Ganesh Balkrishna Bhide (from Associate), Royston Bradshaw, Arthur Herbert Thomas Brazier (from Associate), Ernest James Brunckhurst (from Associate), Eric Hafold Coleman (from Associate), Bernard Crossland (from Graduate), Ernest George Currington, Reginald Charles William Eyre (from Graduate), Richard William George Gandy, Jack Raymond Green, Richard Greinacher, Sidney Clifford Bernard Hailey (from Graduate), John Michael Harrison, Edward John Hidson (from Graduate), Albert Teichmann Howell (from Associate), Bengt Folke Jakobsson, Ronald Leslie Lawrence, Norman Hugh Le Gallais (from Graduate), Arthur Henry Logan, Konstanty Macewicz, Charles Oran Maliphant, Gordon Charles Montague Parris (from Student), Philip William Pilkington (from Graduate), Reginald Charles Sanders (from Student), Norman Francis Searle (from Graduate), Stanley Arthur Stephenson (from Student), Romuald Szukiewicz, Jan Tustanowski, Jeffrey Watkins, Hugh Joseph Wilson (from Associate), David John Wright, Philip Wyndham Wright.

*Associates*

Geoffrey Cyril Ames, Raymond Percy Bench, Gabe Robb Bryce, Raymond Rupert Caveney (from Student), Alfred Edward Charles Coward, Gordon Leonard Derham, John Edgeley, John Sinclair Gibbs, Stanley Heath, Donald Angelo Hewetson, James Horbury, Frederick William Howlett, Geoffrey Cecil Tudor Jones, Thomas Walker Kennedy, Lewis Eric Lang, John Kenneth Marshall (from Student), Edward Alexander Layton, John Richard Neill, Frederick Ewart O'Leary, George James Pearn, Peter George Randell, Harry Christian Salmon, Charles William Edward Ward, Sidney Charles Wybrow.

*Graduates*

Albert William James Adams, Donald Cyril Bain, Paul John Bellerby (from Student), Peter Lawrence Britton (from Student), Michael Broad, Alan Richard Buley, Michael Frederick Burle (from Student), Lawrence Wilfred Chambers, Kevin Edmund Cheverton (from Student), Raymond Close, John Lewis Cutler (from Student), Alan Russell Dare, David Richard Dennis, John Steward Drabble (from Student), Peter Reginald Dymond, Hugh Oliver Ewart (from Student), Arthur Horace Sidney Fernando, Terence John Floyd (from Student), Peter Harold Fredericks, Patrick William Joseph Fullam, Ian Alexander Butler Gaunt (from Student), John Gilchrist, John Colin Green (from Student), Jean Michael Hahn (from Student), Peter William Gerrett Hargreaves (from Student), Roy George Harmer (from Student), Peter Kenneth Hickman, John Edward Howland (from Student), Edward Vernon Hullah (from Student), Gerald David Macdonald (from Student), Frank Ronald Mason (from Student), Derek George Mitchelson, Samuel Edward Nelson, Leonard Eric Norton, Donald George Pearce (from Student), Peter Edward Radcliffe (from Student), William Harper Sleigh (from Student), Reginald Ernest Swinfield, Ronald Albert Swinnerton (from Student), Alwyne Edward Thornton (from Student), Albert William George Utting (from Student), Peter Herbert Stringer Wroe.

*Students*

Raymond Francis Anderson, Patrick Edward Stanbrook Batey, Peter Stanley Beckett, Michael Alan Blaxill, John Alan Caister, William Edward Thomas Cawsey, Graham Dudley Clapp, David Gordon Clark, Derek John Freeman, James Walter Gearing, Michael Eveness Haldane Grant, H. Ronald Harrison, Keith James Henderson, John Dennis Hodge, Ronald George Hudson, Peter Lionel Hughes, John Arthur Beverley Lambert, Peter Marsden, Jack Mawer, Donald George Merchant, Norman James Munro, Brian William Plenderleith, Primo Angelo Lazaro Signorini, Keith Welton Smith, Wallis Parkinson Stack, Saied Zafar.

*Companion*

Mary Theodora Peggy Ward (from Student).

## ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks the gift of an early Mexican book on balloon ascents—"Memorias del Fisico Aeronauta," by D. Adolfo Theodore—presented by H. G. Conway, Esq., Fellow, from his father's library.

The Council also acknowledge gratefully the gift of books from Major B. W. Shilson, Fellow, and back numbers of the Journal from Captain A. N. Barrett, Associate Fellow, Mrs. Walker Sinclair, Companion, and W. Tye, Esq., Fellow.

## ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.a.352—Supersonic flow and shock waves. R. Courant and K. O. Friedrichs. Interscience Publishers, New York. 1948.

A.a.353—Photoelasticity. Volume II. M. M. Frocht. John Wiley. 1948.

B.e.45—Model Sailplane Design. P. R. Bruyne. Percival Marshall. 1948.

D.b.280—The Air League Book. Air League of the British Empire. Foley House Press. 1949.

E.a.19—Heat Engines. D. A. Wrangham. Cambridge University Press. 1948.

E.c.34—Engineering Metallurgy. W. E. Woodward. Constable. 1948.

EE.a.128—Armstrong Siddeley Aircraft Engines Instruction Book Tiger XI.

EE.a.129—Armstrong Siddeley Aircraft Engines Instruction Book Cheetah IX.

EE.a.130—Armstrong Siddeley Aircraft Engines Instruction Book Tiger VI.

EE.a.131—Armstrong Siddeley Aircraft Engines Instruction Book Lynx IVc.
EE.h.40—Herbert Ackroyd Stuart Lecture 1946. The Advent of the Aircraft Gas Turbine. A/Cdre. F. Whittle. University College, Nottingham. 1946.
L.c.32—Airplane Performance and Operation. R. Dixon Speas. McGraw Hill. 1948.
N.d.6—Military and Political Consequences of Atomic Energy. P. M. S. Blackett. Turnstile Press. 1948.
*R.b.267—Memorias del Fisico Aeronauta. D. Adolfo Theodore. Ansvalo, Mexico. 1833.
*X.e.82—American Aviation Directory Fall-Winter 1948. American Aviation Publications, Washington. 1948.

**N.A.C.A. Technical Notes**

1453—*An investigation of aircraft heaters. XXIX—Comparison of several methods of calculating heat losses from airfoils. L. M. K. Boelter, L. M. Grossman, R. C. Martenelli and E. H. Morrin.*
1461—*Influence of crystal plane and surrounding atmosphere on some types of friction and wear between metals. A. T. Gwathmey, H. Leidheiser, Jr., and G. Pedro Smith.*
1505—*The inward bulge type buckling of monococque cylinders. V—Revised strain energy theory which assumes a more general deflected shape at buckling. N. J. Hoff, B. Klein and B. A. Boley.*
1546—*Aerodynamic characteristics of 24 NACA 16-series airfoils at mach numbers between 0.3 and 0.8. W. F. Lindsey, D. B. Stevenson and B. N. Daley.*
1649—*Investigation of a 1/7-scale powered model of a twin-boom airplane and a comparison of its stability, control and performance with those of a similar all-wing airplane. G. W. Brewer and R. W. May, Jr.*
1681—*Critical shear stress of an infinitely long plate in the plastic region. E. Z. Stowell.*
1688—*Dynamometer-stand investigation of the muffler used in the demonstration of light-airplane noise production. K. R. Czarnecki and D. D. Davis, Jr.*
1696—*Chordwise pressure distributions on a 12-foot-span wing of NACA 66-series airfoil sections up to mach number of 0.60. N. E. Wall.*
1698—*Effect of wind velocity on performance of helicopter rotors as investigated with the Langley helicopter apparatus. P. J. Carpenter.*
1700—*The rolling moment due to sideslip of triangular, trapezoidal, and related plan forms in supersonic flow. A. L. Jones, J. R. Spreiter and A. Alksne.*
1703—*Downwash and wake behind untapered wings of various aspect ratio and angles of sweep. H. Page Hoggard, Jr., and J. R. Hagerman.*
1713—*Experimental study of effect of vaneless-diffuser diameter on diffuser performance. G. R. Bradshaw and E. B. Laskin.*
1715—*Mollier diagrams for air saturated with water vapour at low temperatures. R. V. Hansley.*
1717—*Gust-tunnel investigation of a 45 degrees sweptforward-wing model. H. B. Pierce.*
1718—*Influence of leading-edge suction on lift-drag ratios of wings at supersonic speeds. C. B. Cohen.*
1720—*Friction at high velocities of surfaces lubricated with sulfur as an additive. R. L. Johnson, M. A. Swikert and E. E. Bisson.*
1722—*Prediction of the effects of propeller operation on the static longitudinal stability of single-engine tractor monoplanes with flaps retracted. J. Weil and W. C. Sleeman, Jr.*
1723—*A theoretical investigation of the effect of yawing moment due to rolling on lateral oscillatory stability. J. L. Johnson and L. Sternfield.*
1724—*A study of skin temperatures of conical bodies in supersonic flight. W. B. Huston, C. N. Warfield and A. Z. Stone.*
1726—*Spray characteristics of four flying-boat hulls as affected by length-beam ratio. W. W. Hodges and D. R. Woodward.*

1727—*A simplified method for the determination and analysis of the neutral-lateral-oscillatory-stability boundary. L. Sternfield and O. B. Gates, Jr.*

1729—*Flight determination of wing and tail loads on a fighter-type airplane by means of strain-gauge measurements. W. S. Aiken, Jr.*

1730—*Effects of temporal, tangential bearing acceleration on performance characteristics of slides and journal bearings. D. J. Landanyi.*

1731—*High-temperature attack of various compounds on four heat-resisting alloys. D. G. Moore, J. C. Tichmond and W. N. Harrison.*

808—*A method for the calculation of external lift, moment, and pressure drag of slender open-nose bodies of revolution at supersonic speeds. C. E. Brown and H. M. Parker.*

816—*Comparison of wind-tunnel and flight measurements of stability and control characteristics of a Douglas A-26 airplane. G. G. Kayten and W. Koven.*

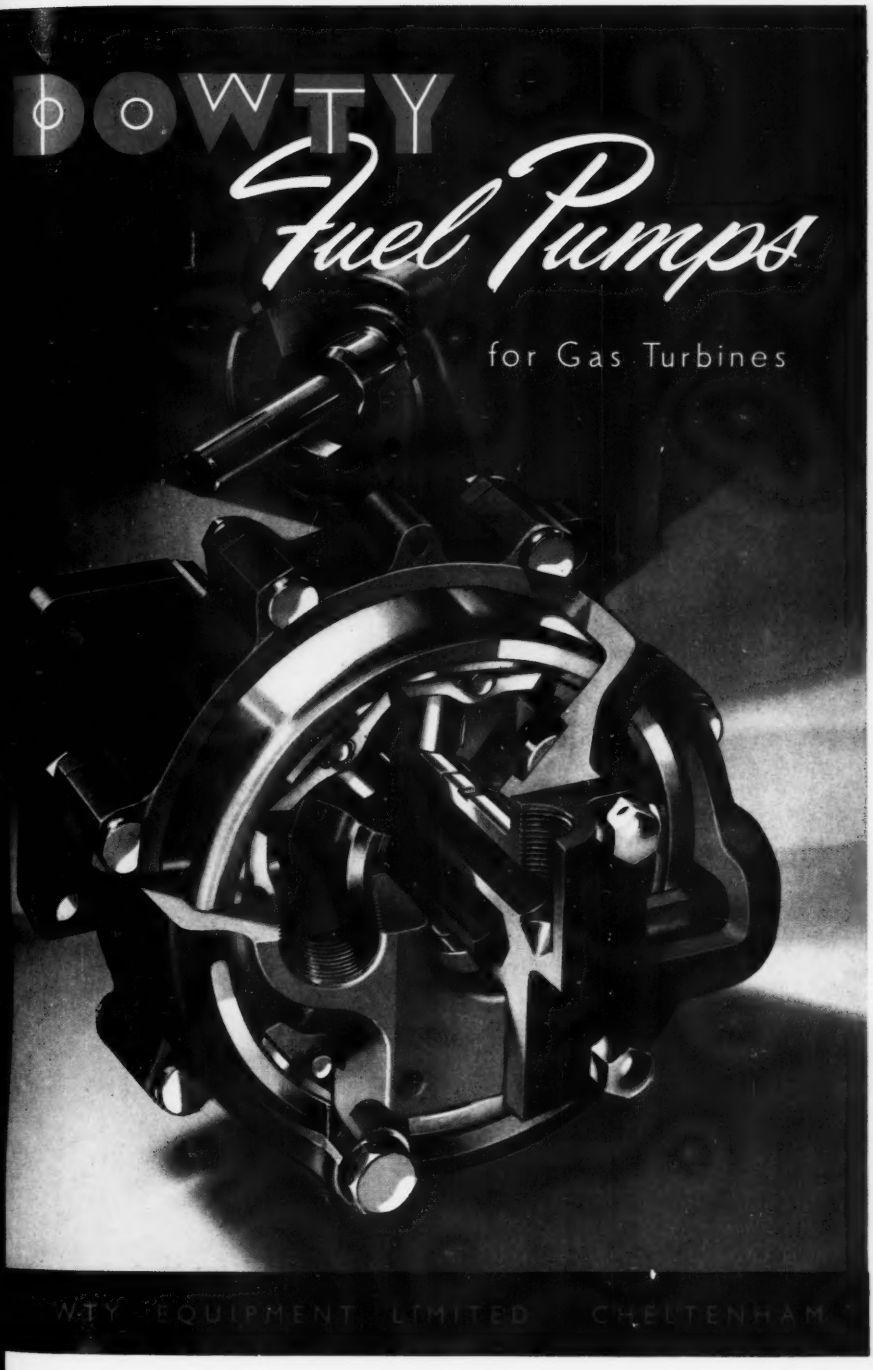
The following reports have also been received:—

**Publications Scientifiques et Techniques du Ministere de l'Air**
*Report No.* 220.

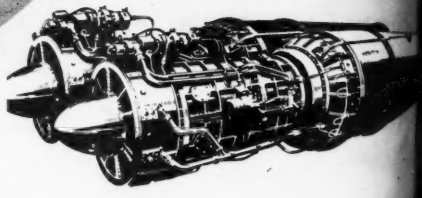
**Flygtekniska Forsolstalten Ffa**
*Report No.* 25.

J. LAURENCE PRITCHARD,
*Secretary.*

Made and Printed in Great Britain by the Lewes Press, Lewes, Sussex.




Printed by the Lewes Pre · (Wightman & Co. Ltd.), Friars Walk, Lewes, England, and Published by The Royal ERONAUTICAL Society, 4 Hamilton Place, London, W.1, England.



# SR.A1

***The world's first jet propelled fighter flying boat***

POWERED BY TWO METROVICK "BERYL" AXIAL FLOW JET UNITS. AS SUPPLIED TO T

## SAUNDERS-ROE

Saunders-Roe Limited, Osborne, East Cowes, Isle of Wight (Cowes 445)